

**GEODATABASE DEVELOPMENT AND GIS BASED ANALYSIS FOR
RESOURCE ASSESSMENT OF PLACER PLATINUM IN THE OFFSHORE
REGION OF GOODNEWS BAY, ALASKA**

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A

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ABSTRACT

Goodnews Bay, southwest Alaska, is known for extensive Pt reserves that have their source in the neighboring Red Mountain. The reserves potentially extend offshore into the Bering Sea. This study aims at developing a geodatabase to integrate all offshore platinum related data collected by researchers and agencies in the past, with the intent to identify data gaps. Based on these data gaps 49 new areas were sampled for Pt and geophysical data were collected in summer 2005. Spatial distribution map for offshore Pt was created using a new Multiple Regression Pattern Recognition Technique (MRPRT) that gave an $R^2=0.76$, a significant improvement from standard GIS based geospatial techniques. Four potential Pt exploration areas were delineated, including one area where drowned ultramafics and buried alluvial channels co-occur. Coastal currents influenced the surficial platinum accumulations, and no clear relation between Pt distribution and sand bars in the far offshore could be established.

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My parents
You have invested your life in me and shown me Jesus,
who is the source of all the blessings I enjoy.
I love you!

1.0 INTRODUCTION

Platinum (Pt) is a vital and expensive commodity. With its current price exceeding \$1000/ounce, it is of greater unit value than gold and has extensive and stable demand. Platinum resources in the United States (US) are rare: One of the largest resources is the alluvial placer deposit at Red Mountain, Goodnews Bay, in south west Alaska, from which at least 22 tons of Pt has been recovered (Barker, 1986).

The properties of platinum, such as fabrication strength, resistance to tarnish and magnificent look have greatly augmented the applicability of this precious metal. Today, outside of its use in elegant jewelry, platinum has found application in industries such as electronics, telecommunication, automobile, aerospace and defense. Considering its application and rarity, the US government declared platinum as a strategic metal at the start of World War-II. Currently the major producers of platinum in the world are South Africa and Russia. The import reliance of US on this foreign-supplied strategic metal is unacceptably high (95%) and any disruption in supply of this metal would make the dependent industries highly vulnerable (Jackson, 1988). Therefore, the need to identify domestic resources of platinum is highly critical for the stability of the economy.

Goodnews Bay, which has been the major source of Pt for the country, has not been mined since the 1980's due to the depletion of shallow economic reserves. Red Mountain, which is considered to be the source rock for platinum in the Goodnews Bay region, is immediately adjacent to the Bering Sea (Harrington, 1919; Hoare and Coonrad, 1961; Mertie, 1969). The proximity of Red Mountain to the Bering Sea indicates a considerable likelihood for offshore Pt accumulations. Based on limited data, the United

States Geological Survey (USGS) estimated the marine Pt placer potential for the Goodnews Bay region at 155 metric tons (Page et al., 1973; Barker, 1986). Several government agencies, individuals, and corporations have tried to assess the marine platinum resource in offshore Goodnews Bay region. Those assessments have neither incisively estimated the resource potential nor delineated more than general areas of interest.

1.1 RESEARCH HYPOTHESES

Considering the regional setting of the offshore region of Goodnews Bay and the processes relating to marine placer formation and their transport, three research hypotheses were formulated for this study. The study area is shown in **Figure 1.1**.

1.1.1 Alluvial Placers

The placer platinum onshore at Goodnews Bay is mostly contained in the Salmon River and its tributaries draining the Red Mountain. However, the southern reaches of Salmon River were poor in platinum contents. Mertie (1940) reconstructed the buried bedrock topography of the Salmon River valley from drill hole data. He recognized that the southern part of the present Salmon River was exposed to glaciation and has been buried by an overburden of 80-100m of glacial till and pre-glacial outwash. Therefore, there is a likelihood of finding paleo buried channels (possible extensions of the ancient analog of Salmon River) in the offshore region of Goodnews Bay. These channels could contain significant placer platinum deposits similar to those identified onshore. It is also

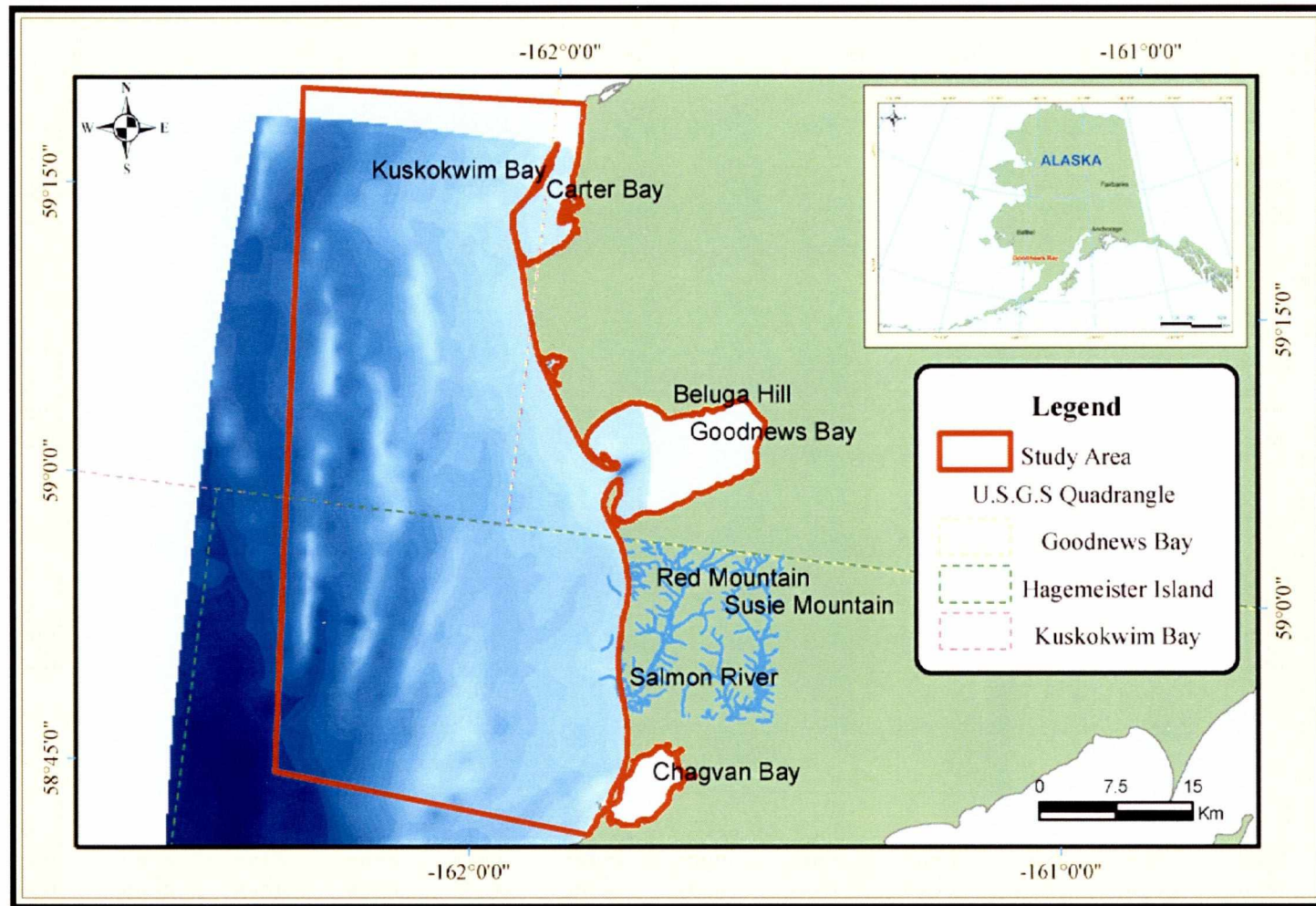


Figure 1.1: Study area; offshore region of Goodnews Bay. It is 2200 Sq. km in area, delineated by the Goodnews Bay, Hagmeister Island and Kuskokwim Bay Quadrangle boundaries of the USGS. The inset shows that Goodnews Bay is in southwest Alaska.

noted from the literature that the Red Mountain, which is an Alaskan type of zoned ultramafic rock, is a large convoluted sill like mass that is repeatedly exposed by one or more north-south (N-S) folds or faults, and at some other places covered by a thin layer of country rock and surface sediments (Barker, 1986). Therefore, there is also a likelihood of buried folded or faulted ultramafic rock existing in the offshore region. If so, channels draining these ultramafic rocks could contain a rich accumulation of alluvial placer platinum. Based on this information, one hypothesis of this research is that the offshore region of Goodnews Bay contains buried channels and drowned ultramafic rocks, and that these channels could be extensions of the Salmon River and its tributaries or channels that drain buried/drowned ultramafic rocks offshore, and would be a potentially good source for platinum.

1.1.2 Modern and Near Modern Processes

It is suggested that the glacial sea level in the study region was about 120m below the present level, 21 Ky B. P (Hopkins, 1967; Manley, 2002). During the Pleistocene glacial-post glacial period, this region has undergone several transgressive and regressive sea level cycles. The study of the nearshore and offshore bathymetry of this region revealed that there are several sand bars offshore, which are aligned parallel or sub-parallel to the present coastline. These sand bars could be submerged paleo-beaches. Based on this information, another hypothesis of this research is that during the transgressive cycles of sea level fluctuations the sand bars would have acted as zones for wave sorting, thus concentrating heavy minerals. Therefore, these sand bars could have

higher platinum placer concentrations. An analogous scenario is observed in the offshore (and onshore) paleo-marine gold placers of the Nome region (Nelson et al., 1972).

1.1.3 Chemical Concentrations

Some of the Pt data collected by Moore (1971) suggest that Pt might occur as chemical concentrates in organic rich marine clays. Supporting this is the report by Rudolph and Moore (1972), who analyzed three flora samples from the onshore region of Goodnews Bay, showing Pt in the range of 3.5 to 6.6ppm, which obviously indicates the amount of leaching that is occurring in this region. Studies have identified that in saline waters both Pt and Pd elements can dissolve and mobilize as chloride complexes with the solubility of Pt favored over Pd (Williams, 2001; Cameron and Hattori, 2005). Therefore, it is hypothesized that the platinum deposits in the offshore region undergo chemical weathering. These chemically weathered complexes would be reworked and entrained by currents and will get deposited in low energy environments heterologous to the placer deposits. Normally heavy minerals of greater size than the silt fraction will get deposited in high energy environments.

1.2 OBJECTIVES

The first objective of this study is to compile and integrate the data from various geophysical and geochemical explorations conducted in the offshore region of Goodnews Bay in order to develop a comprehensive geodatabase for offshore platinum prospects in this region that would serve as a resource for future exploration.

The resource assessment of marine placer deposits is a dynamic and complicated process. In order to decipher this complicated process, to clearly assess the resource and delineate the boundaries of marine deposits, there are several dimensions that need to be studied. For example, understanding of the source rock, the historical sea level fluctuations, the paleo channels, and the weathering and transport processes is needed. The Geographic Information System (GIS) combined with a geodatabase offers a practical solution to integrate data with reference to its geographic location and to visualize and analyze complex problems on a common platform. The second objective of this study is to utilize the geodatabase to evaluate the need for more data collection and collect data if necessary, analyze the new data along with the existing data to test the hypotheses, and then provide a spatial distribution map of platinum and its potential concentrations to serve as a basis for future exploration. The resource estimation and the calculation of the commercial value of platinum in this region were done as part of another Master of Science thesis by Tenorio (2006).

2.0 BACKGROUND

The Red Mountain is considered to be the source rock of platinum in Goodnews Bay. The Red Mountain being immediately adjacent to Bering Sea poses considerable likelihood for both onshore and offshore deposits. However, time and again historic events such as Bering land bridge (Beringia), sea level fluctuations and glaciation have bridged the onshore and offshore deposits. The research for offshore placer platinum deposits in this region cannot be complete without the understanding of the topics such as onshore geology, geomorphology, glaciation, sea level fluctuation, source rock, modes of transport, depositional environment, and so on. This chapter is a brief description of the literature surveyed pertaining to the above topics.

2.1 STUDY AREA

The study area of this research is the offshore region included in the Goodnews Bay, Hagemeister Island, and Kuskokwim Bay Quadrangles. Goodnews Bay is in southwestern Alaska (**Figure 1.1**). It is located approximately 700 km (420 miles) west-southwest of Anchorage, and 200 km (120 miles) south of Bethel. The study area is encompassed between latitudes $58^{\circ} 44' 19''$ N and $59^{\circ} 21' 27''$ N, and longitudes $161^{\circ} 48' 00''$ W and $162^{\circ} 26' 15''$ W (**Figure 1.1**). It is approximately 2200 sq km in the Kuskokwim Bay, west of Red Mountain. The present coastline which forms the eastern

boundary for the study area was formed ~ 3-5 ky ago. Prior to that, the coastline was farther away towards the west, leaving the present study area as part of the onshore landforms (Hopkins, 1967; Manley, 2002).

2.2 GEOLOGY

2.2.1 Surface Geology/Lithology

The geology of Goodnews Bay was first mapped and described by Harrington (1919). In fact, the discovery of Pt placers in the 1920's drew the attention of several geologists to the area. A detailed geologic map of Goodnews Bay mining district was provided by Mertie (1938). Subsequently, the general geology and composition of platinum group metals (PGM) was described (Mertie, 1940; Mertie, 1969; Mertie, 1976; Southworth, 1986).

The three principal factors observed from the surface geology of the onshore of Goodnews Bay by Mertie (1940) are that the regional rocks generally strike northeastward, and the degree of regional metamorphism though variable is higher towards the south. The continuous lithologic character implies that similar lithologic characteristics to onshore might exist in the offshore also.

Mertie (1976) noted that the placer deposits are mostly Pt-Fe alloy inter-grown with chromite and as subordinate Os-Ir alloy. However, it was also found that the ratio of these elements varied in different parts of the onshore region. Bird and Clark (1976) analyzed the dunite and olivine-chromitites from this region. This study recognized that the chromite contains more iron than usually found in alpine or stratiform complexes.

These observations together with general geology of the area and the classification criteria of Jackson and Thayer (1972) and Bird and Clark (1976) indicated a similarity of Red Mountain to the Alaskan type zoned complexes.

In the past, platinum mining in this region was in the form of placers and most of them have been recovered from two paystreaks in the valley of the Salmon river (Mertie, 1976). Mertie (1969) describes some of the characteristics of these paystreaks, that bench paystreak consists of beds of clay, with an average gravel content of 20 percent. These gravel layers are present as inlaid seams and thin strata, from 30cm to 100cm thick. Moreover, Mertie (1969) also recognized that considerable platinum occurs within the overlying clay and associated gravels.

2.2.2 Structural Geology

Structurally the onshore region of Goodnews Bay area is divided into two terranes, the Togiak and the Goodnews (Jones et al., 1981). The Togiak terrane has a structural assemblage of volcanic and volcanoclastic rocks intermixed with chert (Barker et al., 1988). The age of Togiak terrane ranges from late Triassic through early Cretaceous. The Goodnews terrane consists of pillow basalt, chert, limestone, blueschist, greywacke and ultramafic rocks of early Paleozoic to early Cretaceous in age (Hoare and Coonrad, 1978). Box (1984) interprets that the Goodnews terrane has been structurally emplaced against and beneath the northwestern edge of the Togiak terrane along an active southeast dipping subduction zone. Later, the Goodnews terrane was intruded by

the Goodnews Bay ultramafic complex after the accretion. The ultramafic rocks of the Goodnews terrane are the source rock for platinum in this region.

2.3 GEOMORPHOLOGY

2.3.1 Topography

The Goodnews Bay region has a subdued terrain, with landforms related to Holocene continental glaciation (Barker and Lamal, 1989). The three dominant features that characterize the topography of the onshore region at Goodnews Bay are: Red Mountain to the west, along the coast line rising to an elevation of 570 m, 11.3 km long and 1.5 km wide; Salmon River valley and its tributaries, located centrally at a minimum mean elevation of 61 m; and Susie Mountain rising to an elevation of 551 m to the east (**Figure 2.1**). Mertie (1940) observed that the northwest flank of Red Mountain is much steeper than the southeastern flank, which he attributed to the flowing of two continental ice sheets along the northwest flank of Red Mountain, scouring the bedrock and entrained till into the offshore region.

The major rivers in the Salmon River valley are the Salmon River and Smalls River. It was the Salmon River and its tributaries draining the Red Mountain that contained most of the placer platinum which was mined onshore over the last 60 years. The number of small elliptical pools towards the southwest indicates that the Salmon River valley has a poor drainage in the south. The poor drainage is an indicator of the limited movement of the alluvial placer platinum in the south of Salmon River.

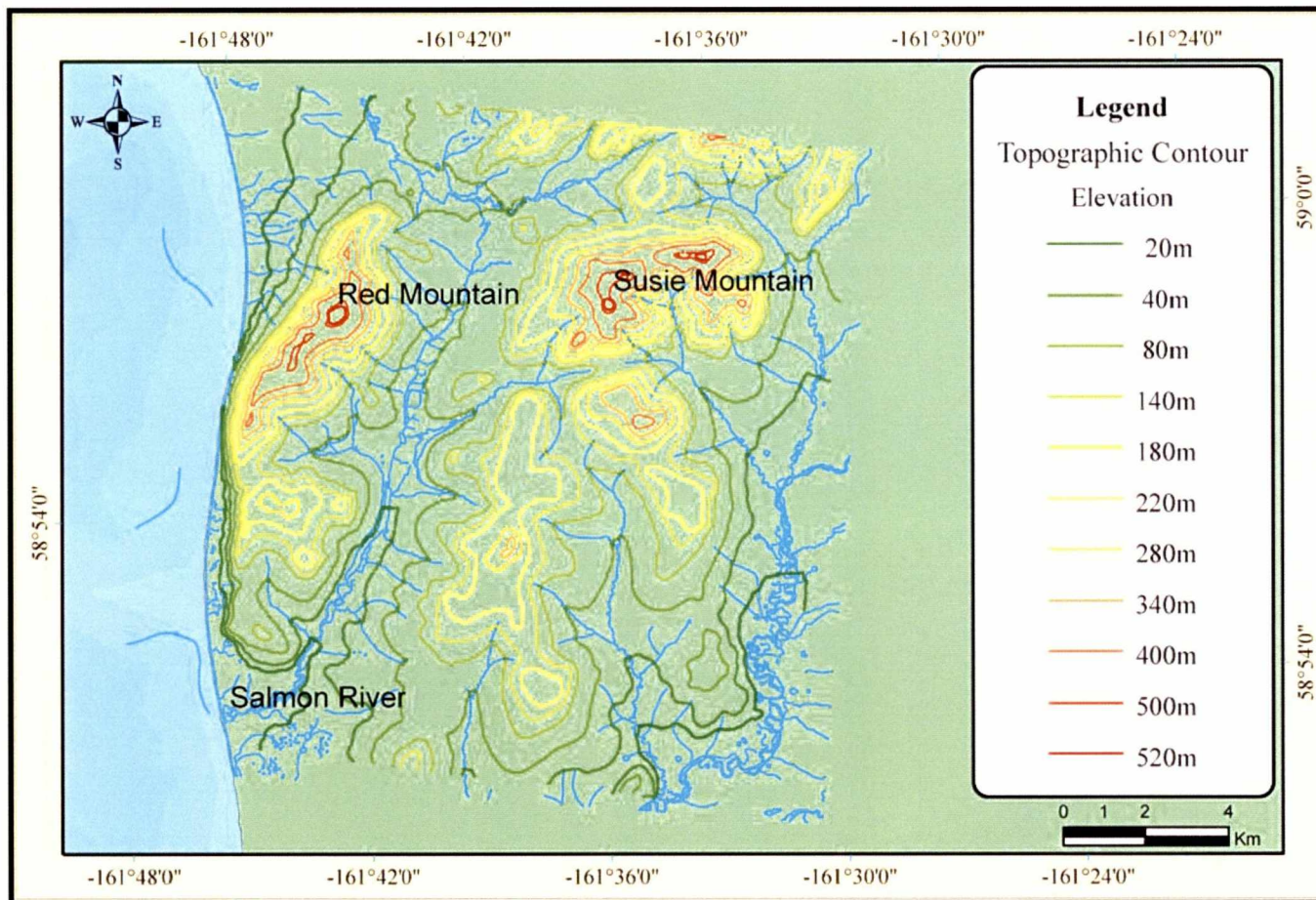


Figure 2.1: The three dominant topographic features in the onshore region of Goodnews Bay, which has been the location for platinum placer mining in the past. The Red and Susie Mountains are the source rocks for platinum in this region. Red Mountain, which lies adjacent to the Bering Sea, is a likely source for offshore Pt accumulations

Mertie (1940) reconstructed the buried bedrock topography of Salmon River using drill hole data from the Salmon River valley. In this exercise, two channels were identified. One channel extended from Medicine Creek south to Chagvan Bay, where it is approximately 80 m deep and 350 to 500 m wide. Mertie (1940) noted that the buried channel is floored by weathered and decomposed bedrock overlain by oxidized preglacial sediments. The second buried channel, on the west side of Salmon River Valley, is a sharp, 150 m wide, V-shaped gorge, with a depth not more than 35 m. The channel is incised in fresh, unweathered bedrock and is overlain by nonweathered gravel of glacial origin. The most obvious interpretation is that prior to the glacial epoch (pre ca. 1.8 Ma) the Salmon River and associated placer platinum flowed south and deposited its load into the Bering Sea near present Chagvan Bay (**Figure 1.1**).

2.3.2 Bathymetry

The topography defines the transportation and the deposition of placers onshore while the bathymetry governs behavior of the currents and the impinging waves offshore. The currents play a major role in the reworking of placer deposits in the offshore environment. Hence, it is critical to have good bathymetric data to study offshore placer deposits. For this study, bathymetric data were compiled from the Americas BlueChart v. 5, Garmin Mapsource. However, BlueChart did not allow for obtaining the output in digital format. Therefore, data were captured for the study area as screen shots, and a mosaic of these shots was developed. The data points obtained by screen shots were then digitized in ArcGIS 9.0 and further rasterized and contoured by the nearest neighbor

interpolation technique. **Figure 2.2** shows the bathymetry of the study area. Barker et al. (1988) observed that the Bering Sea is a flat featureless bottom interrupted by scattered ice rafted boulders. This is also implied from **Figure 2.2**. The water depth is shallow and does not exceed 8 m at mean low tide, to a distance of 10 km off the coast, and varies up to 3 m within tidal fluctuations except at the narrow channel at the entrance of Goodnews Bay, which is 21 m deep. Beyond 8 km from the coast, several sand bars are visible which are parallel or sub parallel to the present coast. These sand bars might represent paleobeaches. If so, during the sea level transgression these sand bars would have been the sites for heavy minerals concentration by waves. A similar deposition is found in the marine and onshore environments of Nome in Northwestern Alaska, where beach placer gold was found (Nelson et al., 1972; Zelenka, 1988).

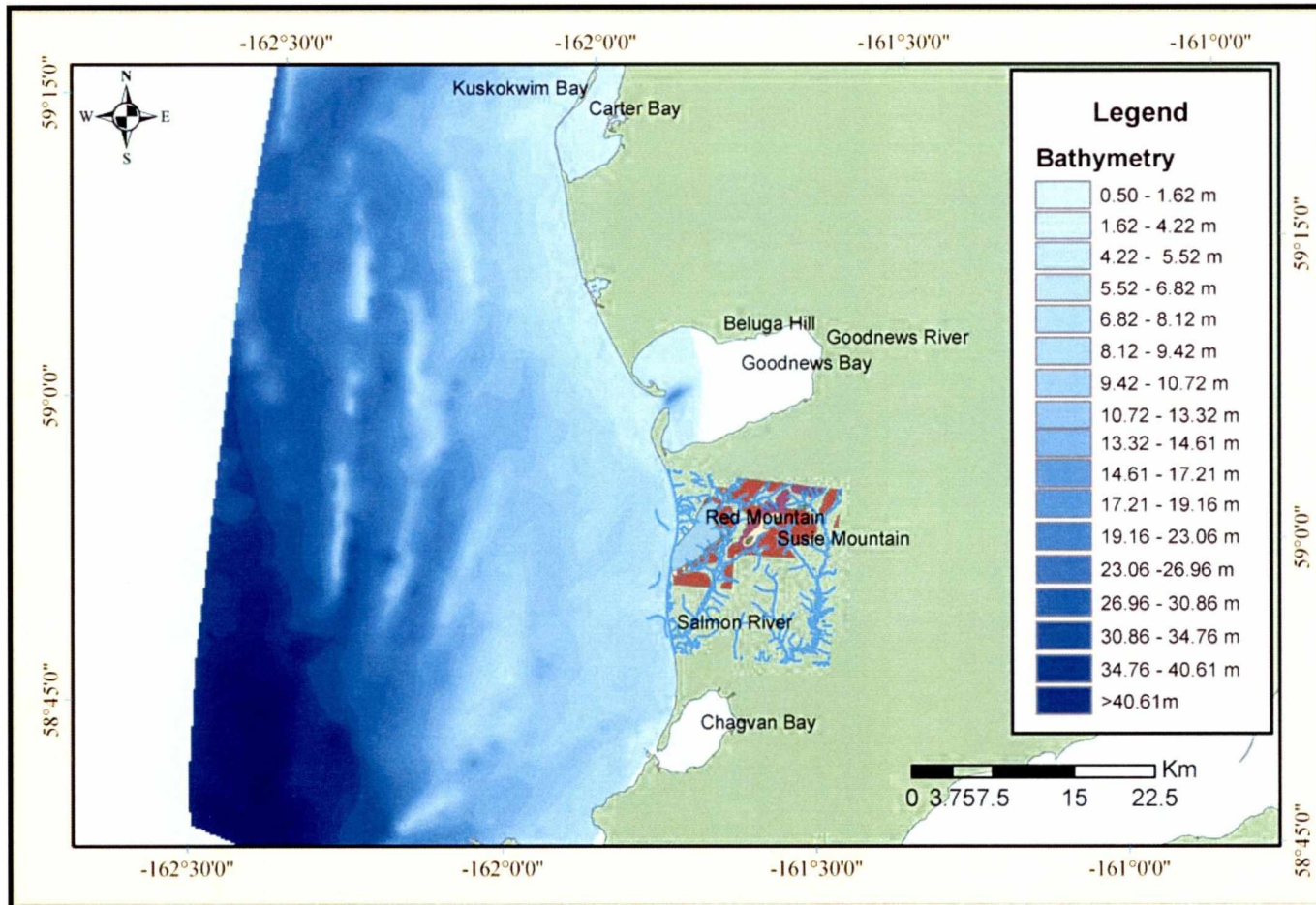


Figure 2.2: Bathymetry of the study area. This bathymetric map was developed from the America BluChart v5, Garmin Mapsource data. Several sand bars parallel and sub parallel to the present coastline can be seen as brighter blue linear features trending in the north-south direction. These features trending in the north-south direction might be representing paleostrandlines.

2.4 GLACIATION HISTORY

The two factors that are recognized to have strongly influenced the geomorphology of this region are the past glacial history and the present periglacial climate (Ulrich, 1984; Zelenka, 1988).

2.4.1 Glaciation

Some of the topographic features discussed in Section 2.3, such as the steep slope of the western face of Red Mountain and buried bedrock topography of Salmon River, testify that glaciation has played a major role in the present landform of this region. The glacial history of this region was studied by Mertie (1940), Hoare and Coonrad (1961), Porter (1967), and Kaufman et al., (2001). Though these studies have different views on the number of glacial advances that have occurred, their age and distance from the offshore, all the studies undoubtedly show that there has been glaciation in this region and scouring of material from onshore to offshore. There are several interpretations on the extent of glacial boundaries to the offshore. The maximum extent of Pleistocene glaciers is shown in **Figure 2.3** (Kaufman et al., 2001; Kaufman and Manley, 2004). According to these data, the maximum limits of Pleistocene glaciers extend approximately up to 60 km west of the present coastline and have an estimated age of 5 ky (Kaufman and Manley, 2004). Mertie (1940), and Hoare and Coonrad (1961) believed that this area was glaciated only once and the glacial boundary was from the north end of the Salmon River valley and coastal region along the northwest side of the Red

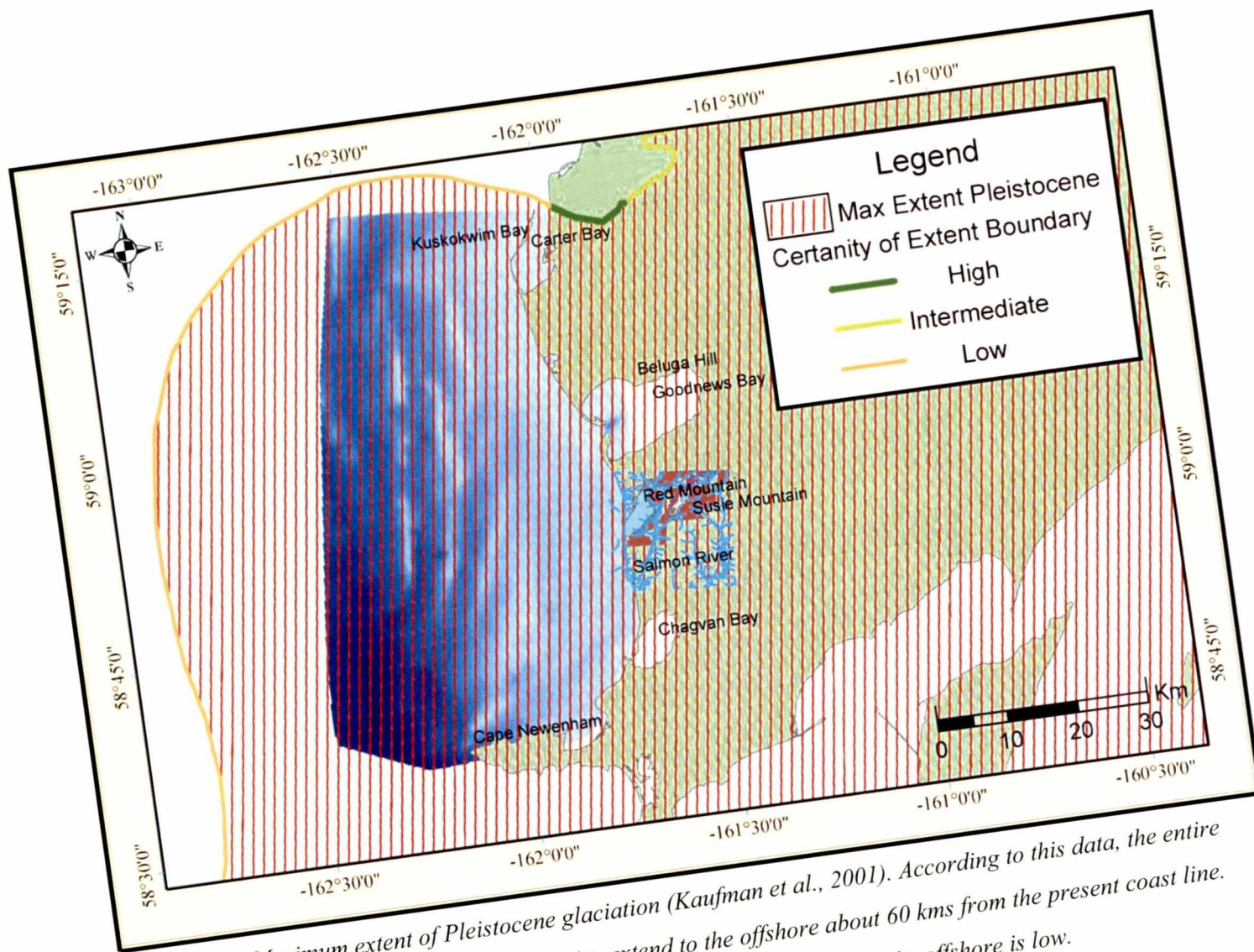


Figure 2.3: Maximum extent of Pleistocene glaciation (Kaufman et al., 2001). According to this data, the entire study area is glaciated and the maximum limits, extend to the offshore about 60 kms from the present coast line. However, the certainty factor assigned to the determination of the glacial limits offshore is low.

Mountain, extending farther south to the east of Chagvan Bay. This conclusion was primarily based on photointerpretation.

A detailed study of glaciers of this region, conducted by Porter (1967), suggested that the area around Red Mountain has undergone at least four glacial advances causing erosion of its margins and transport of the sediments to the coast along the Kineghak and Goodnews River valleys. The steep slope of the west side of Red Mountain is attributed to glacial scouring which has probably removed the sediments from this side and transported them offshore. These glacial advances were given local names which are, from oldest to youngest, the Kemuk glaciation, the Clara Creek glaciation, the Chagvan glaciation and the Unaluk glaciation.

Out of the four glacial advances, the Clara Creek glaciation is the most extensive. At the glacial maximum, it is considered that the ice from the Goodnews Bay area flowed south into the headwater regions of Salmon River, and ice from the Chagvan Bay area moved north into the lower reaches of the Salmon River valley. The two lobes from the north and the south came about 7.24Km (4.5 miles) of each other (Porter, 1967). At that time the normal southward drainage in the valley was blocked by the advance of Chagvan Bay lobe. This advancement of the Chagvan Bay lobe from the south and the Goodnews Bay lobe from the north would have resulted in the ponding of melt water in the Salmon River valley, thus closing off the valley by ice from both the ends. As the ice retreated, the impounded water escaped to the southwest direction. As a result, the present Salmon River was formed. The observation by Porter (1967) supplements Mertie's (1940), who

found that the present Salmon River towards the south was formed after glaciation and the channel flowed towards the Chagvan Bay before glaciation (discussed in Section 2.3.1).

Mertie (1976) observed, from the onshore mining data, that as the Salmon River reached Medicine Creek, approximately where the Chagvan Bay lobe was assumed to have advanced north according to Porter (1967), there was a sudden depletion in the placer platinum value (Mertie, 1976). The most obvious interpretation is that there was no release of placer platinum from the source rock after the Clara Creek glaciation, and release was before this geologic event. This implies that the extension of the Salmon River valley in the south (from Medicine Creek), buried due to glaciation, might have platinum values similar to those of deposits mined north of Medicine Creek. If the extension of this channel to the offshore can be identified, it should contain a high concentration of platinum.

Porter (1967) and Ulrich (1984) estimated that the glacial material was deposited at least 1.5 km offshore from the present coast. However, the recalculation of these data by Zelenka (1988) suggests that these materials might have been deposited up to 5 km offshore of the present coast. **Figure 2.4** shows the limits of glaciation as interpreted by Ocean Mining Company, prepared by Porter (1967).

The study of the morphology and distribution of the gold and platinum grains from the beach and coastal bluffs suggest that the two elements were introduced to the

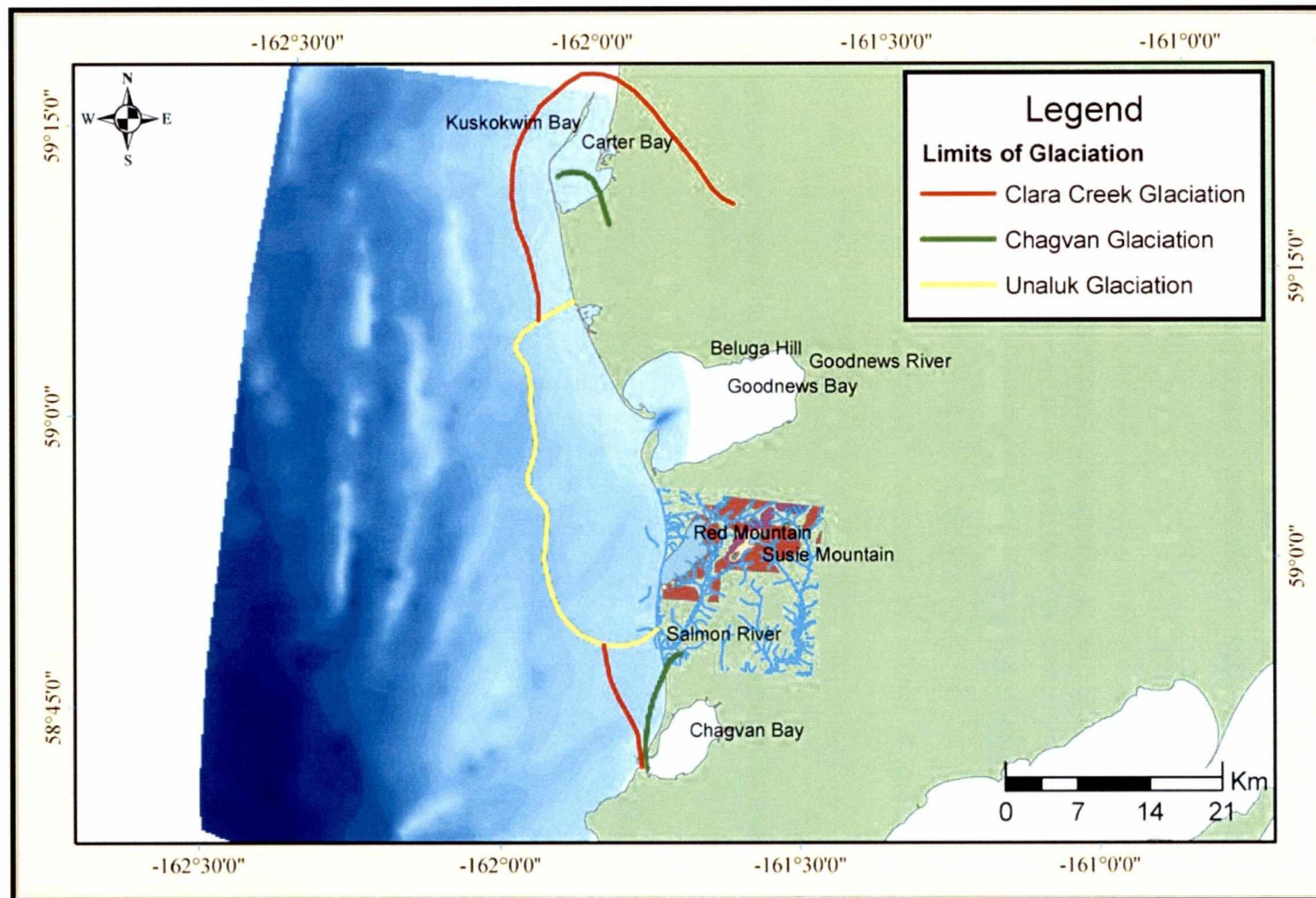


Figure 2.4: Glacial extents of the three different glaciations of the Pleistocene epoch as interpreted by Ocean mining company (unpublished reports) and Porter (1967). According to this data the maximum limits of glaciation has extended only up to 5 km from the present coast.

coastal area by glacial action (Howkins, 1988). But, the platinum grains had undergone less physical abrasion and dilution than the gold, suggesting that gold might have traveled farther than platinum due to glacial movement. Later, the rise in temperature caused the glaciers to melt, in turn increasing the sea level and drowning the vast land area.

2.4.2 Beringia

“Beringia” is a land bridge that existed during the last glacial lowered sea level approximately 21 ky B.P, connecting Alaska with Russia (Manley, 2002). Budd (1979) noted that at that time the water level was about 120m below the present level. However, due to the melting of world glaciers and continental ice sheets over the following millennia, the rise of sea level occurred, and this rise caused the flooding and drowning of the Bering land bridge. The change in coastline due to this rise in sea level after the last ice age is shown in **Figure 2.5**. The present coastline was formed about 5-3 ky B.P. The study area which is west of Red Mountain has also undergone several marine transgression and regression cycles consequent to respective melting and expanding of glaciers. These cycles have periodically inundated an extensive low relief coastal plain extending several km into the Kuskokwim Bay (Barker, 1986). A correlation between the glacial history of the Goodnews Bay region and the sea level fluctuations is given in **Table 2.1** (after Porter, 1967; and Howkins, 1988).

The sea level regressions might have resulted in the formation of submerged paleo-strand lines. These strand lines might have a high potential for heavy mineral

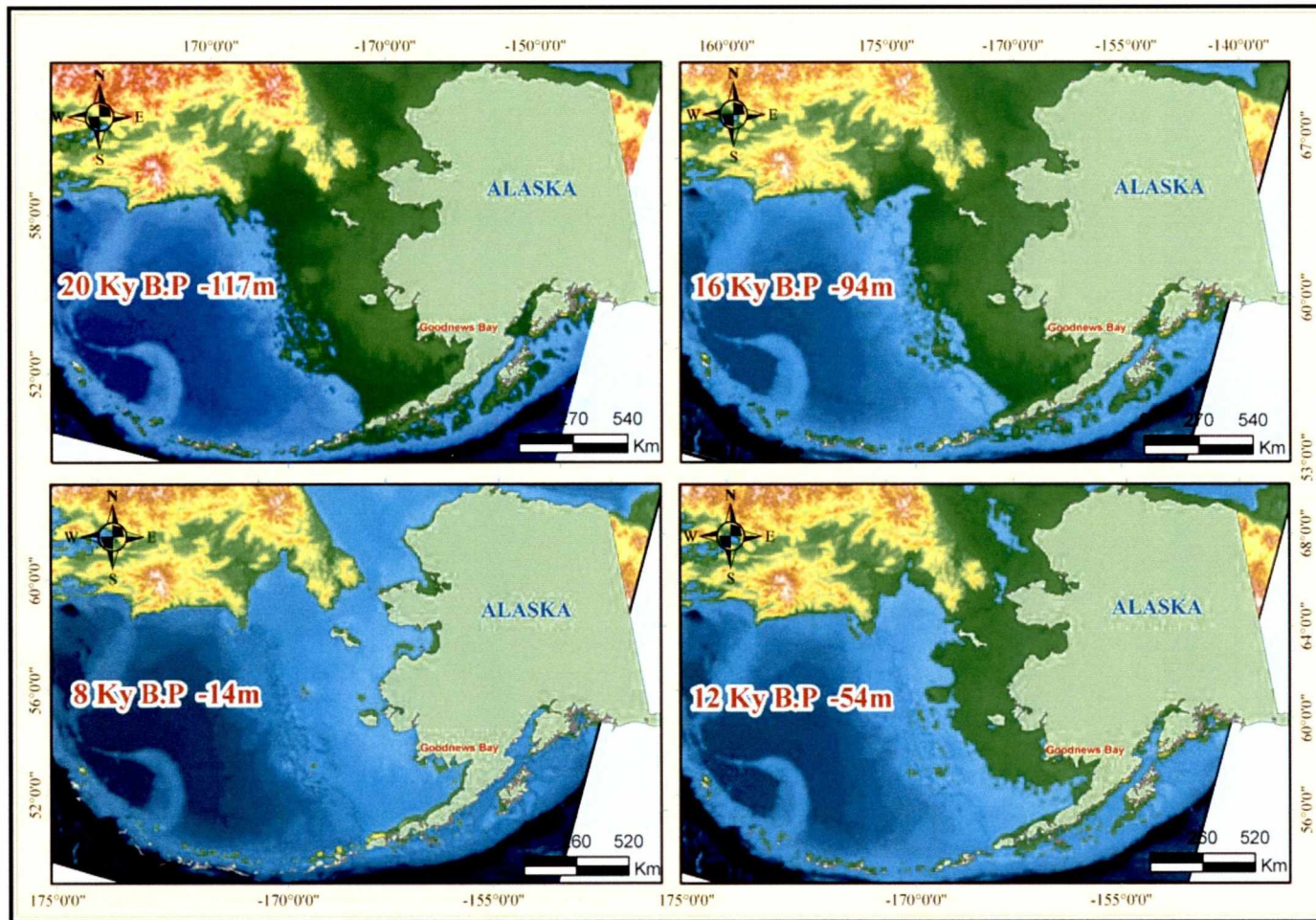


Figure 2.5: Change in coastline due to rise in sea level after the last ice age (Manley, 2002). It is observed from this data that there existed a land bridge between Alaska and Russia up to 12 Ky B.P and the present coastline was formed approximately 3-5 Ky B.P.

Table 2.1: Summary of glacial history and sea level change (after Porter, 1967; and Howkins, 1988)

Drift	Age (years BP)	Ice Movement and Sea Level Change
Kemuk		Between the Pliocene and the Pleistocene epoch, the Bering-Chukchi plateau sank and sea level rose. Little direct evidence of glaciation. Chagvan Bay ice pushed up the Salmon River Valley and deposited drift unconformably. Ice most likely filled Goodnews Bay.
Clara Creek	> 175 ky	Following a long interglacial period, renewed glaciation caused a decrease in sea level. Salmon River cut into Kemuk drift and bedrock. The entire area was ice covered except the middle Salmon River Valley. The Inter-lobe area was filled by a lake of which there is no evidence. The two piedmont lobes may have collapsed in the vicinity of present Salmon River mouth. Recessional morainal ridges are evident at both ends of the Salmon River mouth.
Chagvan	> 45 ky	Chagvan Bay ice moved to the mouth of the Salmon River valley diverting flow to the west. Glacially induced lowering of the sea level induced down cutting into Clara Creek drift. Goodnews Bay ice reached the Smalls and Salmon River divide, diverting outwash into the Salmon River valley. Retreating ice left accurate recessional moraines in the upper and lower Salmon River valley. Deep erosion of Clara Creek drift occurred in Chagvan Bay
Unaluk	> 8910	Sea level dropped and Salmon River entrenched itself into bedrock. Large arcuate moraines are visible east of Chagvan Bay.

concentration due to the lighter minerals getting winnowed out and the heavier ones getting trapped. This type of deposit has been found to be an important offshore concentrator of gold in the Nome district (Nelson et al., 1972; Zelenka, 1988). As discussed earlier, available bathymetric data suggest the possibility of paleo-strand lines/sand bars parallel and sub-parallel to the present coast in the study area.

2.5 PLACER DEPOSITS

2.5.1 Source Rock

No placers can be formed without an appropriate source rock; therefore the first step of any placer exploration is to identify the source rock. The explorations to identify drowned source rocks have been limited and uncertain. However, studies onshore have identified that there are two rocks of economic interest in this region: granites and the ultramafics. The granites are considered to be the source rock for gold, and the ultramafics for platinum (Harrington, 1919; Hoare and Coonrad, 1961; Mertie, 1969). Mertie (1969) reported that these rocks are of the Tertiary age. The ultramafics in this region are oriented as North-East trending elongated lobes. The limited magnetic and gravity survey data of this region suggested that the Smalls and Salmon River exposures and the Red Mountain and Susie Mountain masses are all part of a same large, convoluted ultramafic sill-like mass which has been repeatedly exposed by one or more N-S folds or faults, and at some other places covered by a thin layer of country rock and surface sediments (Barker, 1986). Until now, no studies have identified the lode deposit of platinum in this region. However, in 1976, Bird and Clark found a platinum inclusion

in the chromite of Red Mountain. Based on this finding they confirmed that Red Mountain is the source of platinum placer in this region. But later studies by Corral Creek Corporation have identified a platinum inclusion on the Susie Mountain (Van der Poel and Hinderman, 2001). Today it has been conclusively established that the ultramafic rocks in this region are part of the same large mass that has been repeatedly exposed and covered (Barker, 1986). This indicates that there is a high probability that this large convoluted mass extends into the offshore region as well, and is now covered by the glacial deposits and submerged by the Bering Sea.

2.5.2 Modes of Transport

In the Goodnews Bay region the transportation of heavy minerals is mainly caused by weathering, fluvial action and glaciation (Ulrich, 1984). The maximum sediment transport activity in the streams occurs as snowmelt which takes place from mid May through mid June. The burst of energy caused by the melting of snow in rivers for this short period is considered to be far more erosive and has the potential to transport more material than when the stream has a more uniform flow (Ebleton and King, 1975).

The long distance movements of heavy minerals such as platinum occur only when the minerals are very fine grained. In such a case, they are moved by swift water currents and may move downstream for great distances. With the exception of some conditions, placer deposits of heavy minerals should be found within a few km of the source rock due to their relatively high specific gravity. If placer deposits are found a long distance away from the source rock it leads us to assume either that there are several

source rocks present in close proximity, or that metals have been distributed by repetitive lowering of the base level of erosion (sea level fluctuations), glaciation, or that the placer grains are very fine.

Longshore transport by coastal currents is probably the most important agent of transport for heavy minerals offshore (Zelenka, 1988). The coastal current map for the area developed by Hunter et al. (1979) is shown in **Figure 2.6**. Fox and Davis (1976) noted that sediment transport is influenced by waves that are normal, storm generated, and tidal. The magnitude and direction of waves approaching the coast depends upon the weather pattern (Fox and Davis, 1976). Moreover, the path of the waves relative to the coast determines the direction of the littoral drift. The magnitude of a wave combined with its angle of approach establishes the velocity of the long shore currents and the exact rate of transport. The rate of coastal current transport has not been determined in the Goodnews Bay region.

Bond (1982) studied the current meter data obtained from the United States Air Force installation at Cape Newenham. It indicates that most of the sediment transport is attained during the late spring, summer and early autumn when wave and longshore currents are most influenced by the weather in the Aleutian Islands. It is pointed out that during these months the storm approach angle is from the south and southwest. The approach of waves to the coast in these months produces a net long shore drift and

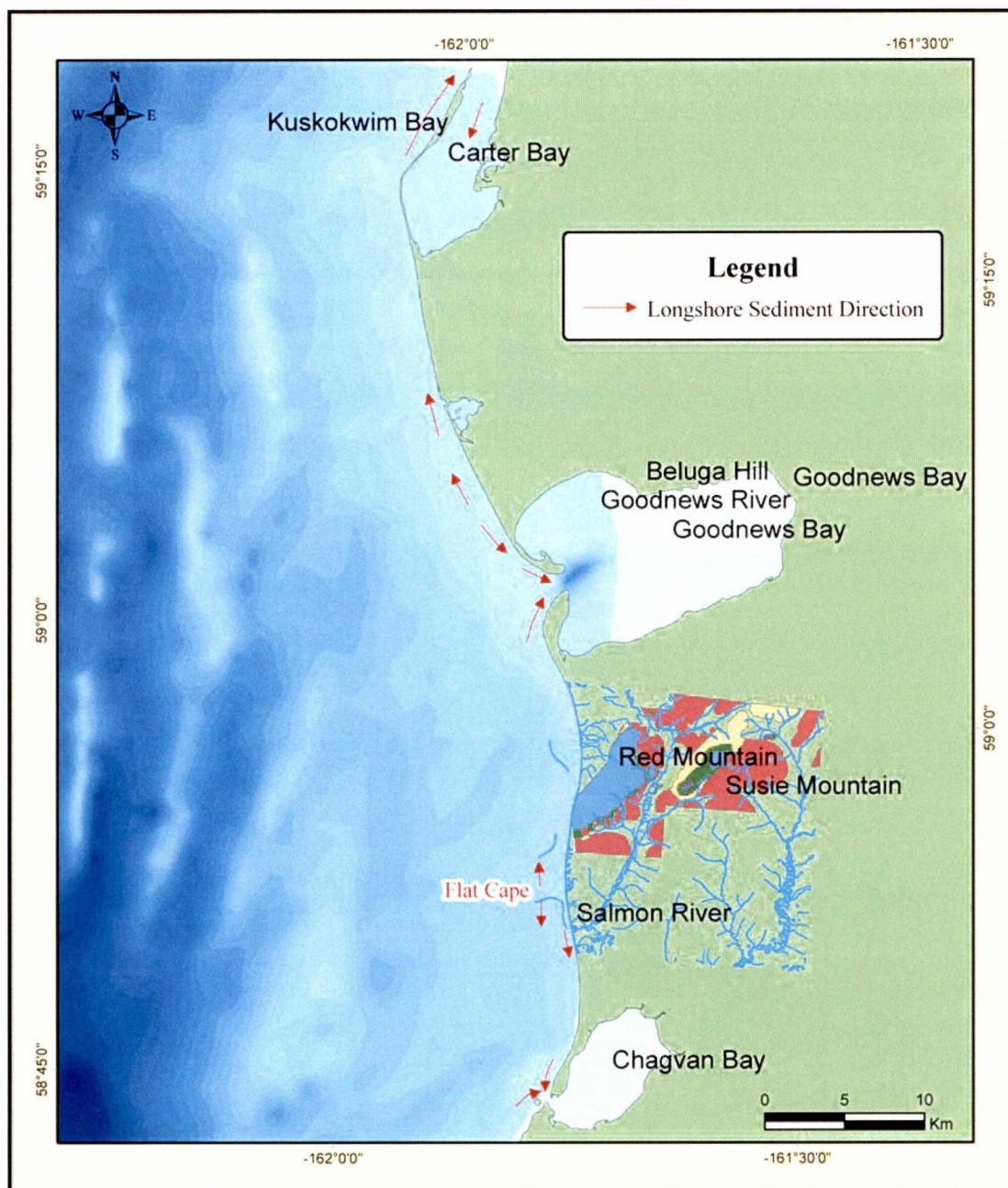


Figure 2.6: Longshore sediment transport direction (Hunter et al., 1979). The net longshore drift and sediment transport is in the northward direction from Flat Cape. Due to the refraction of waves at Flat Cape, it also generates a longshore current in the southward direction.

sediment transport in northward direction from Walrus point. Evidence of this can be seen in the buildup of two curved spits forming the entrance to Goodnews Bay. The refraction of the waves at the Flat Cape/Walrus Point headland generates a longshore current in a southward direction. This causes the southward movement of sediments along the coast from the Walrus Point headland. Evidence for this can be seen in the formation of the spit at the north side of the entrance to Chagvan Bay.

Mardock and Barker (1991) studied the mechanism of transport of placer PGM in the Goodnews Bay region. They attribute it to two contrasting theories of mechanical deposition and accretion. Traditionally in the process of mechanical deposition, the PGM are composed exclusively of primary minerals which are removed from the host rock during the weathering cycle. These grains are mechanically abraded and partially decomposed during the transport and eventually get deposited as placer material. During these processes the grains undergo surface leaching to some extent.

Coastal erosion is a mode of mass yielding of material from the onshore to the offshore regions. It can be readily seen by the concentration of large boulders accumulated along the foreshore region at the base of the cliff at Red Mountain (Wakeland, 1973). Ulrich (1984) calculated that the shoreline has recessed a total of 1760m from the close of last glaciation (approximately 8900 years B.P).

Barker (1986) observed two distinct features using the scanning electron microscope (SEM) analysis of 35 gold grains. The first feature is that they lacked alloy elements other than silver, and the second is that they were of unusually high gold

fineness, averaging 920 (22 karat) with some samples even as fine as 999 (24 karat). The possible explanation given by Barker (1986) for this high fineness is seawater leaching. Recently, it was recognized that in saline waters platinum can dissolve as chloride complexes (Cameron and Hattori, 2005). In brief, chemical weathering could also be a major mode of transport of heavy minerals in this region but no studies have identified the form in which the minerals are entrained by currents and concentrated or precipitated. However, placer deposits and chemically weathered material would have different depositional environments.

2.5.3 Depositional Environments

From the onshore mining history of Goodnews Bay it is understood that only PGM placers of fluvial origin have been economically mined. However, in the offshore region, several promising depositional environments have been observed. The fundamental difference between the depositional environment of platinum placers and platinum dissolved as chloride complexes is that the former, with a high density, tend to form in marine environments with energies high enough to separate the heavy minerals from other sediments, whereas the latter gets deposited in low energy marine environments. The different possible high energy depositional environments for placers in the offshore region of Goodnews Bay have been studied in detail by Berryhill (1963), Owen (1975), Welkie (1976), Coonrad et al. (1978), Bond (1982), Ulrich (1984) and Zelenka (1988). In this study, the major placer depositional environments under

consideration would be areas proximal to drowned ultramafics, buried paleo-channels, paleo-strand lines and shoal deposits.

3.0 GEODATABASE DEVELOPMENT

In order to develop the Goodnews Bay geodatabase, it was important to trace back the history of the discovery of platinum in this region and identify the various agencies that have been involved in the offshore and nearshore explorations of platinum. Once the agencies were recognized, data from their work were gathered from the literature, archives and unpublished reports.

3.1 HISTORY OF PLATINUM IN GOODNEWS BAY

The history of the platinum deposit in Goodnews Bay begins in 1926, when Walter Smith, an Eskimo, found platinum at the mouth of Fox Gulch, which is a headwater tributary of Platinum Creek (Mertie, 1969). He informed his friend Henry Whuya that he found white gold (Reed, 1933). Whuya, with the help of his friend Thorsen, sent a sample of this new discovery to the US Bureau of Mines lab in Fairbanks, Alaska for analysis, and determined that this was high grade platinum. Subsequently, several mining companies mined platinum from this region until 1986, when shallow economic reserves became limited and the companies failed to meet the federal environmental standards. **Figure 3.1** shows Fox Gulch, where platinum was discovered, and the locations where most onshore mining was carried out. It is observed that the onshore deposit of placer platinum was mostly restricted to the Salmon River valley which is the major drainage of the ultramafic rocks in this region.

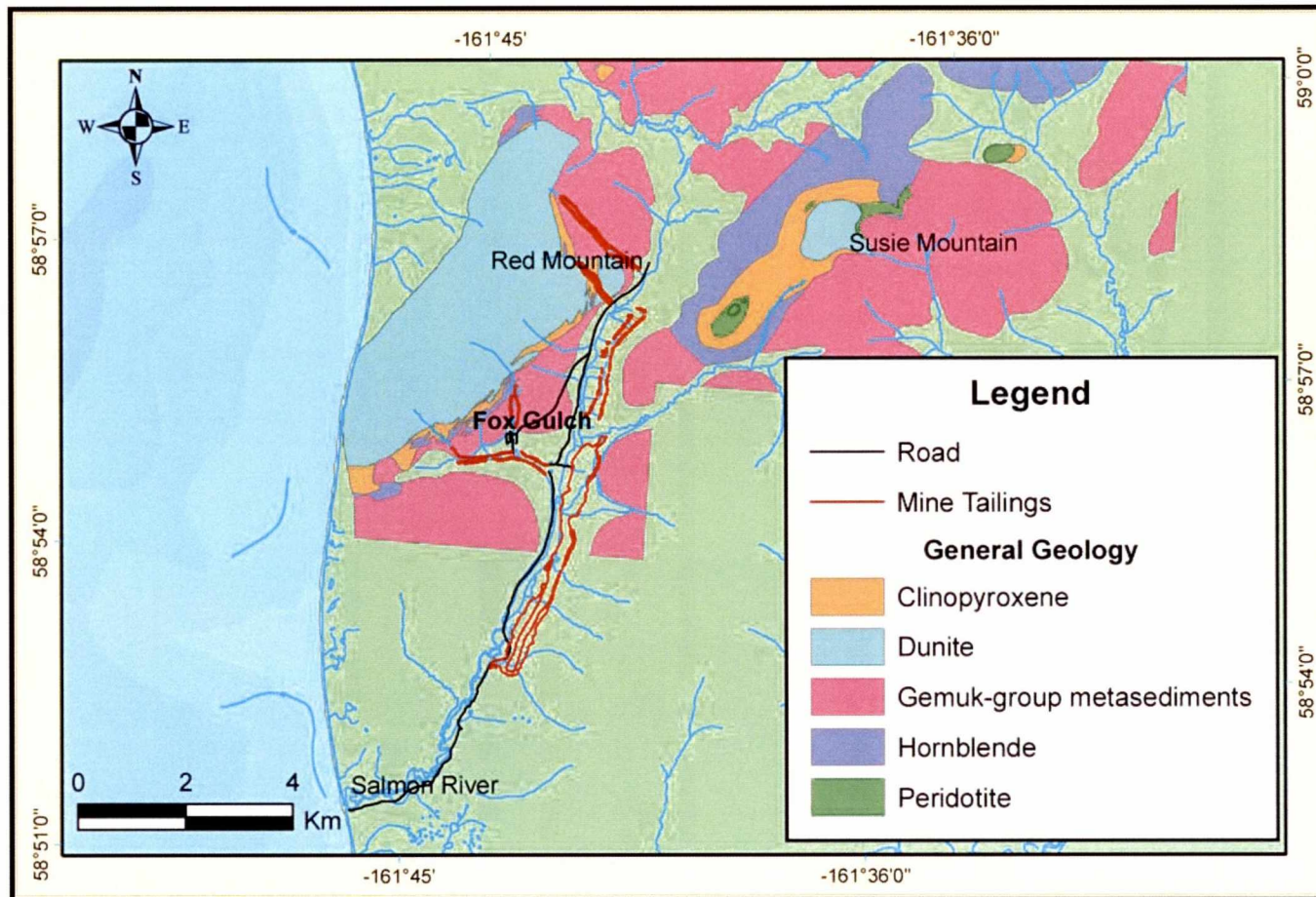


Figure 3.1: Map showing Fox Gulch, where Walter Smith first found platinum in Goodnews Bay region. It also shows the mine tailings of the onshore mining operations in this region, illustrating that the placer platinum deposit onshore was mostly restricted to the Salmon River valley which is the major drainage of ultramafic rocks in this region (Source: Poel and Hinderman, 2001).

3.2 PREVIOUS INVESTIGATIONS FOR NEARSHORE/OFFSHORE PLATINUM PLACERS

The marine placers mostly occur on the continental shelf and are principally formed by the submergence of alluvial and/or beach placers (Evans, 1993). Considering the fact that the Goodnews Bay offshore/nearshore region has undergone several sea level fluctuations submerging the entire “Bering Land Bridge,” it attracted several organizations and industries looking for potential offshore/nearshore deposits immediately after the discovery of onshore platinum reserves.

However, their studies were inconclusive, and data were generally not available (Mertie, 1940; Barker and Lamal, 1989). The limited data available from this region are from the studies by Inlet Oil Corporation (IOC) and the USGS in late 1960s and early 1970s, and the United States Bureau of Mines (USBM) and Western Gold Exploration and Mining Limited Partnership (WestGold) in late 1980s. These studies can be divided into two categories: the precious metal explorations and the geophysical explorations. The precious metal explorations comprised of core/grab samples collected from the offshore/nearshore area and analyzed for platinum and gold. The geophysical explorations were comprised of magnetic and seismic investigations. Evidently, there was a need to integrate the data from these various explorations to assess the need for more data collection and to aid in a comprehensive resource assessment. An available solution to this need was to develop a geodatabase, which allows integrating the data with respect to geographic location and analyzing it in a Geographic Information System (GIS)

environment. Hence, a geodatabase was developed for the offshore/nearshore region of Goodnews Bay to integrate all the available data and to assess the platinum resource distribution.

3.3 GEODATABASE

A geodatabase is a geographic database, which provides a common data access and management framework for consolidation and evaluation of existing geospatial data using GIS analysis tools. In this study, the geodatabase was developed using a personal geodatabase format of ESRI's ArcGIS 9.0. There are various advantages of integrating and storing geographic data using a geodatabase. It is not only a collection of data, but also a crucial representation of their relationship to each other. Therefore, building a geodatabase enables investigators to relate themes (datasets) and situations that were previously separate (Aronoff, 1995). Moreover, having the data collected and organized in one location (geodatabase) reduces the redundancy and duplication, and decreases the maintenance cost (Broberg and Keskinen, 2004). In addition, the data can be transferred to the interested parties very easily in digital format and can be analyzed in a GIS environment.

The problem of modeling the marine placer deposit of the offshore region of Goodnews Bay is both complex and dynamic. Problems of this nature can only be modeled when several attributes are overlaid and analyzed at the same time. The ability offered by GIS to overlay several layers of data and analyze all of them in a single analysis is unmatched by any other method (Aronoff, 1995).

3.3.1 Modeling a Geodatabase

The modeling of a geodatabase can be divided into three categorical design stages: conceptual, logical and physical design (Jones, 1999; Longley et al., 2002; Arctur and Zeiler, 2004). Conceptual design is the stage where the key data layers that need to be included in the geodatabase are identified, the geographic representation type for the identified layers is determined, and the map scale and storage accuracy of the data are finalized. The geospatial attributes can be represented in two ways in the geodatabase. The data that are discrete are modeled as point, line or polygon feature classes, whereas continuous surface data are modeled as a raster dataset (Chrisman, 2002).

In a logical design, valid values and ranges are identified; subtypes are created to control the behavior and model relationships. Further, this leads to the development of an initial design style for the entire geodatabase.

The physical design is when the conceptual and logical design are executed to load the database with data. In the physical design process, as the data get loaded into the geodatabase, each dataset is tested and the geodatabase is refined accordingly. As the final step of physical design, when all the datasets have been loaded into the geodatabase various reporting methods such as the schema diagram, reports and data models are developed.

The personal geodatabase of the Goodnews Bay offshore platinum prospect is attached as a CD in the pocket affixed to the back cover. The geodatabase schema

diagram that was developed using the Arc-Catalog add in command, Geodatabase diagrammer and Microsoft Visio, which is also located in the pocket.

3.3.2 Elements of the Geodatabase

The structure of the Goodnews Bay geodatabase is given in a figure in the pocket. The different elements of the geodatabase such as subtypes, domains, feature dataset, feature classes, relationship class etc. are discussed in the following sections. The Goodnews Bay geodatabase has 36 feature classes in 6 feature datasets and 4 stand alone feature classes. It also has 5 domains and 8 relationship classes. The spatial reference used for the geodatabase is Albers equal area projection, with datum North American 1927 and spheroid, Clarke 1866. All units of measurement are in S.I units.

3.3.2.1 Subtypes

Subtypes are created to store tables and feature classes of the same type, which have similar behaviors and attributes. In the Goodnews Bay geodatabase, subtypes are created to control the data entry of precious metals. For example, currently there are only five organizations in the geodatabase that have contributed precious mineral data. Therefore, a subtype of these five organizations has been created. However, in the future as more organizations contribute data, these organizations can be added as a new subtype.

The advantage of having subtypes is that, the geodatabase can cater to each organization's different way of reporting the data. Some organizations have a separate Job Id, Field Id and Lab Id, whereas, some others have just the Field Id. In the future,

when additional data are integrated into the geodatabase, by choosing the right subtype, only the attributes of that specific subtype will be prompted to be entered. Since the personal geodatabase created for the Goodnews Bay region is an open geodatabase, which can be expanded as more data are collected in the future, the creation of a subtype would help to enter the data from an organization in their own specified manner and still have all of the data under a specific feature class.

3.3.2.2 *Domains*

Domains are used to restrict the values allowed to be entered in any particular attribute of a table, feature class or subtype. There are two types of domains that can be specified: they are attribute domains and range domains. There are five domains in the Goodnews Bay geodatabase. The advantage of having domains is that, for example, United States Geological Survey can be entered as USGS or US Geological Survey. However, if the attribute field value is known *a priori*, a domain can be created and specified so that, for example, the United States Geological Survey will be only entered as USGS. In that way, all the data in the geodatabase will be entered uniformly, which will facilitate better data querying.

3.3.2.3 *Feature Dataset*

The feature classes, relationship classes and tables of thematic similarity or geometric relationships are grouped into one dataset known as the feature dataset. In the Goodnews Bay geodatabase there are six feature datasets. They are Boundaries, Geology,

Geophysics, Offshore, Physical and Precious metals. Each of these feature datasets, have several object classes.

The feature classes of different feature datasets are discussed below.

Boundaries

The feature dataset, “Boundaries” is a collection of various shapefiles of polylines and polygons. These polylines and polygons represent various boundary conditions. The various feature classes in this feature dataset for this study are:

Coastline

“Coastline” is a simple polygon feature class. It depicts the coastline of Alaska. These data were originally developed at a scale of 1:63,360. The source of the data is <ftp://ftp.dnr.state.ak.us/asgdc/adnr/coast63.zip>. The feature class consists of a total of 37338 polygons. They were included in the geodatabase to define the eastern boundary of the study area.

Offshore Lease

“OffshoreLease” is a simple polygon feature class. It represents the offshore mining leases and prospecting permits for locatable or potentially locatable minerals on state-owned tide and submerged lands. The source of the data is <http://mapper.landrecords.info/SpatialUtility/SUC?cmd=mdandlayerid=3>. It has a total of 166 polygons. The “offshorelease” helps to verify the distribution of platinum in a particular lease boundary.

Onshore Mining Claims

“OnshoreMiningClaims” is a simple polygon feature class. It delineates the number of state mining claims, prospecting sites, and federal claims either selected or patented and totally located within each section of the state of Alaska. The source of the data is Alaska Department of Natural Resources - land records information section. It has a total of 7564 polygons. This feature class enables the determination of the distance between the onshore mining claims and potential offshore platinum sites.

Placer

“Placer” is a simple polygon feature class. It draws the various placer district boundaries in Alaska. Districts refer to the name of a group of geologically and geographically related placer deposits, as derived from published sources or from general usage. The source of the data is Alaska department of natural resources (ADNR), GIS unit. The feature class includes a total of 94 polygons.

Quadrangle

“Quadrangle” is a simple polygon feature class. It depicts the boundaries of the USGS quadrangles covering Alaska, at a scale of 1:250,000. The source of the data is <ftp://ftp.dnr.state.ak.us/asgdc/adnr/qmqa.zip>. The feature class has a total of 150 polygons. It helps to study the extent of the study area into different quadrangle boundaries.

State Limits

“Statelimits” is a simple polyline feature class. It delineates the boundary between the state and the federal waters. These data were developed by creating a 4.8 km offset to the coastline data. This feature class permits distinguishing the platinum in state and federal waters.

Study Area

“StudyArea” is a simple polygon feature class. It draws the study area limits for the offshore platinum assessment study at Goodnews Bay. These limits were based on the research needs, data availability and the testing of research hypotheses.

Topographic Boundary

“TopoBoundary” is a simple polygon feature class. It depicts the quadrangle boundaries for inch to the mile topographic maps. The source of the data is <ftp://ftp.dnr.state.ak.us/asgdc/adnr/itma.zip>. These data were originally developed at a scale of 1:63,360. This feature class has a total of 3007 polygons.

Geology

The feature dataset “Geology” is a collection of various shapefiles of polylines and polygons. These polylines and polygons represent various geological features. The various feature classes in the feature dataset for this study are:

Geology of Alaska

“GeologyAK” is a simple polygon feature class. These data represent the polygon shape and associated attribute data derived from the 1980 geologic map of Alaska compiled by H.M Beikman and published by the USGS. The source of the data is <http://agdcftp1.wr.usgs.gov/pub/usgs/geology/beikman.tar.gz>. The feature class has a total of 5069 polygons. It will help in studying the various lithologic classes in the onshore region and their significance to the distribution of platinum.

Geology of Goodnews Bay

“GeologyGNB” is a simple polygon feature class. These data represent the lithologic units mapped by Alaska Earth Science (AES) and Southworth (1986). The data were provided as a GIS shapefile by Calista Corporation (Foley et al., 2004). The feature class has a total of 68 polygons. These data have more details with respect to Goodnews Bay than the general geology map of Alaska.

Glacial Limits

“GlacialLimits” is a simple polyline feature class. It depicts the glacial limits as interpreted by Ocean Platinum Company (OPC). These data were obtained from a confidential report submitted to the Department of Natural Resources in 1970 by OPC. The feature class was developed as a GIS shapefile by scanning the original report and digitizing the glacial limits in ArcScan. The data were originally developed at a scale of

1:250,000. The feature class has a total of 5 polylines. This represents the interpretation of the glacial history of this region by Porter (1967).

Maximum Pleistocene Limits

“MaxPleistoceneLimits” is a simple polygon feature class. These data portray the maximum extent of the Pleistocene glaciation developed by Manley and Kaufman (2002) as part of the Alaska paleoglacier atlas. The source of the data is http://instaar.colorado.edu/QGISL/ak_paleoglacier_atlas, v1. The feature class has a total of 125 polygons.

Certainty of Pleistocene Limits

“PleistoceneCertainty” is a simple polyline feature class. These data represent the confidence in the maximum extent of the Pleistocene glaciation at different locations developed by Manley and Kaufman (2002). It is categorized into three confidence levels, which are high, intermediate and low. The source of the data is http://instaar.colorado.edu/QGISL/ak_paleoglacier_atlas, v1. The feature class has a total of 245 polylines.

Geophysics

The feature dataset “Geophysics” is a collection of various shapefiles of points, polylines and polygons, which represent various geophysical data collected from the onshore and offshore regions of Goodnews Bay in the past. The various feature classes in the feature dataset for this study are:

Magnetic Contour 2005

“MagContour05” is a simple polyline feature class. It portrays interpolated magnetic data contour lines from the UAF/MMS “Platinum Cruise 05” (Refer Chapter-4). The feature class has a total of 249 polylines. It shows the variation in the magnetic properties of different materials offshore.

Magnetic Contour 1988

“MagContour88” is a simple polyline feature class. It depicts interpolated magnetic contour lines from 1985, 1986 and 1988 published by Barker and Lamal (1989). These data were developed as GIS shapefile by scanning the published map, and digitizing the magnetic contours in ArcScan. The feature class has a total of 16 polylines.

Magnetic Raw Data 2005

“MagRawData05” is a simple point feature class. It represents raw magnetic data from the UAF/MMS “Platinum Cruise 05.” The feature class has a total of 149980 points. The polyline feature class “MagContour05” was developed from these data.

Magnetic Raw Data 1978

“MagRawData78” is a simple point feature class. These data were collected in 1971 in the Goodnews and Hagemester Island quadrangles and subsequently released by the Alaska Division of Geology and Geophysical Survey (ADGGS). The interpretation of these data were published by Griscom (1978). The feature class has a total of 61213

points. These data will help in studying the change in the magnetic properties of different materials onshore and also will permit comparison with the offshore.

Magnetic Raw Data Calista

“MagRawDataCalista” is a simple point feature class. It depicts the aeromagnetic data survey carried out by Alaska Earth Science (AES) and Southworth (1986) in the onshore region of Goodnews Bay. These data were provided as GIS shapefile by Calista Corporation (Foley et al., 2004). The feature class has a total of 75211 points.

Seismic Facies Map 2005

“SeismicFacies05” is a simple polygon feature class. It represents the interpretation of the seismic data from the UAF/MMS “Platinum Cruise 05.” The interpretation was done by Golder Associates, Seattle. The feature class has a total of 11 polygons. These data help in studying the structural geology of the offshore region.

Side Scan Sonar Surficial Sediments 2005

“SideScanSonarSurficialSediment05” is a simple polygon feature class. It portrays the interpretation of the side scan sonar data from the UAF/MMS “Platinum Cruise 05.” The interpretation was done by Golder Associates, Seattle. The feature class has a total of 5 polygons. These data help in studying the surficial sediment patterns and their correlation with the distribution of platinum.

Track Line 2005

“TrackLine05” is a simple polyline feature class. It represents the track line for the geophysical survey carried out by UAF/MMS as part of the “Platinum Cruise 05.” It has a total of 2 polylines. These data identify the areas where the geophysical survey was carried out in 2005.

Track Line 1988

“TrackLine88” is a simple polyline feature class. It depicts the track line for the aeromagnetic data survey carried out by Alaska Earth Science (AES) and Southworth (1986). These data were provided as a GIS shapefile by Calista Corporation (Foley et al., 2004). The feature class has a total of 12 polylines. These data identify areas where geophysical survey was carried out in 1988.

Offshore

The feature dataset “Offshore” is a collection of various shapefiles of points, polylines and polygons, which represent various features of interest such as bathymetry, channels, current direction, strandlines, ultramafic rocks, etc. in the offshore region of Goodnews Bay. The various feature classes in this feature dataset are:

Bathymetry Contour

“BathymetryContour” is a simple polyline feature class. It portrays the bathymetric contour data developed by the method of nearest neighbor interpolation. The source data for the interpolation were the bathymetric point values. The feature class has

a total of 337 polylines. The bathymetric data are important in understanding the offshore geomorphology.

Bathymetry Point Data

“BathymetryPointValues” is a simple point feature class. It depicts the bathymetric point values. The method used to develop these data is explained in Section 2.3.2. The feature class has a total of 1000 points. The bathymetric contour data were developed from this data.

Buried Channels

“BuriedChannels” is a simple polyline feature class. It represents buried paleofluvial channels identified using limited acoustic basement data collected by Barnes in 1969 for the USGS (Barnes, 1986). These data were published by Zelenka in (1988). The GIS shapefile was developed by scanning the original map published by Zelenka (1988), and digitizing the buried channels in ArcScan. The feature class has a total of 25 polylines.

Longshore Sediment Transport

“LongshoreSedimentTrans” is a simple polyline feature class. It represents interpreted directions of net longshore sediment transport along the Alaskan mainland coast of the Bering Sea (Hunter et al., 1979). The GIS shapefile was developed by scanning the original map published by Hunter et al. (1979), and digitizing the transport direction in ArcScan. The feature class has a total of 12 polylines.

Paleostrand Lines

“PaleoStrandLine” is a simple polyline feature class. It portrays paleostrand lines as interpreted by Zelenka (1988) from available bathymetric data. The GIS shapefile was developed by scanning the original map published by Zelenka (1988), and digitizing the paleostrand lines in ArcScan. The feature class has a total of 7 polylines. These data help us to determine, by comparison with the platinum prediction map, whether these strandlines are favorable locations of placer deposits.

Possible Drowned Ultramafic

“PossibleDrownedUltramafic” is a simple polyline feature class. It depicts the possible drowned ultramafic rocks interpreted from the geophysical data. This interpretation is from the published work by Barker and Lamal (1989), and from the unpublished report of Western Gold Exploration and Mining Limited Partnership (WestGold) prepared by Howkins (1988). The GIS shapefile was developed by scanning the original map published by Barker and Lamal (1989) and the report by Howkins (1988), and digitizing the possible drowned ultramafic rocks in ArcScan. The feature class has a total of 11 polylines.

Sand Mud Ratio Goodnews Bay

“SandMudRatioGNB” is a simple polygon feature class. It portrays the sand/mud ratio inside the Goodnews Bay. These data were generated and published by Wakeland (1973). The GIS shapefile was developed by scanning the original map published by

Wakeland (1973), and digitizing the map in ArcScan. The feature class has a total of 13 polygons. These data help in finding the correlation between the platinum concentration in the bay and the surficial sand/mud ratio.

Shoal Enrichment

“ShoalEnrich” is a simple polyline feature class. It represents shoal enrichments as interpreted by Zelenka (1988). The GIS shapefile was developed by scanning the original map published by Zelenka (1988) and digitizing the shoal enrichment in ArcScan. The feature class has a total of 2 polylines. These data, together with the platinum prediction map, helps in determining whether these shoal deposits have higher placer platinum concentrations.

Tide Ridge

“Tide Ridge” is a simple polyline feature class. It depicts tide ridges as interpreted by Zelenka (1988). The GIS shapefile was developed by scanning the original map published by Zelenka (1988) and digitizing the tide ridges in ArcScan. It has a total of 3 polylines. These data together with the platinum prediction map help in identifying the significance of these tidal ridges in concentrating placer platinum.

Physical

The feature dataset “Physical” is a collection of various shapefiles of polylines and polygons, which represent various physical features of interest in the onshore region of Goodnews Bay. These features might not be directly involved in the analysis of the

offshore placer platinum distribution. However, these physical features together with the platinum prediction map will provide critical information such as whether the onshore channels are constantly transporting placer platinum offshore, proximity of onshore mine tailings to the offshore deposits, etc. The various feature classes in the feature dataset used for this study are:

Mine Tailings

“Mine Tailings” is a simple polygon feature class. It portrays the mine tailings from the onshore mining operations for platinum that lasted from the late 1920’s to the mid 80’s. These data were provided as a GIS shapefile by Calista Corporation (Foley et al., 2004). It has a total of 60 polygons.

Alaskan Rivers

“RiversAK” is a simple polygon feature class. These data were developed by the Alaska Department of Natural Resources (ADNR) by combining rivers from several digital charts of the world. The dataset was further clipped to the state of Alaska boundary. The data were developed at a scale of 1:1,000,000. The source of the data is <ftp://ftp.dnr.state.ak.us/asgdc/adnr/rvrml.zip>. The feature class has a total of 6401 polygons.

Goodnews Bay Rivers

“RiversGNB” is a simple polyline feature class. It depicts the rivers in the Goodnews Bay area. These data were provided as a GIS shapefile by Calista Corporation (Foley et al., 2004). The feature class has a total of 693 polylines.

Precious Metals

The feature dataset “Precious Metals” is a collection of point shapefiles. These points represent various locations of precious metal values (both platinum and gold) available from the offshore region of Goodnews Bay. The various feature classes in the feature dataset used for this study are:

Gold

“Gold” is a simple point feature class. This is a collection of samples from the seabed (<1meter deep) collected by various organizations for the study area. The source of the data is discussed in Section 3.4b (Precious Metal Explorations). These are either grab or core samples. The feature class has a total of 403 data points. These data would help an exploration company, if they were developing a mine plan for platinum in this region, to look for the potential of secondary elements (gold in this case) that can be mined with platinum.

Platinum

“Platinum” is a simple point feature class. This is a collection of samples from the seabed (<1meter deep) collected by various organizations. These are either grab or core

samples. The source of the data is discussed in Section 3.4b (Precious Metal Explorations). The feature class has a total of 477 points. These data have been used to develop the platinum prediction map for the study area.

Stand Alone Object Classes

There are 4 stand alone tables in the geodatabase. These tables, as such, don't have geospatial reference. However, they are connected with feature classes that have geospatial reference through relationship classes. For example, the feature class platinum only has platinum values up to a depth of 1m. However, some locations have platinum values at greater depth ($> 1\text{m}$ in depth). Therefore, these values are kept as separate, stand alone object classes, so that if someone is interested in these values they can obtain them. They are kept as stand alone object classes because not all the elements of the feature class have values of platinum below 1m. The four tables are:

Inlet Oil Drill Data of Platinum

“IO_Drill_Data_Pt” is a table containing platinum values obtained from drill hole data, which was analyzed at 30cm intervals. These data were collected by Inlet Oil Corporation in 1969 and were recovered from Dr. Moore's collection (Moore, 1969). The maximum depth to which the samples were analyzed was 16m. The table has a total of 42 entries.

Geology Code Alaska

“GeoAKcode” is a table describing the different geologic map units. It corresponds to the geologic units identified by H.M. Beikman in his 1980 geologic map of Alaska. It has a total of 184 entries. The source of the data is
URL:<http://agdcftp1.wr.usgs.gov/pub/usgs/geology/beikman.tar.gz>

West Gold Drill Data of Gold

“WG_Drill_Data_Au” is a table containing gold values obtained from drill hole data, which were analyzed at 1 meter intervals. These data were collected by WestGold in 1988. The maximum depth to which the samples were analyzed was 21 meters. the table has a total of 30 entries.

West Gold Drill Data of Platinum

“WG_Drill_Data_Pt” is a table containing gold values obtained from drill hole data, which were analyzed at 1 meter intervals. These data were collected by WestGold in 1988. The maximum depth to which the samples were analyzed was 21 meters. the table has a total of 30 entries.

3.3.2.4 Relationship Class

As objects in the real world have associations with other objects, the objects in the geodatabase can also have particular associations with other objects in the database. These are known as relationships in the geodatabase and they are stored in relationship classes (Booth et al., 1999). These relationships can be between spatial objects (feature

and feature class) or/and non-spatial objects (table). The advantage of these relationship classes is that if a person is interested in a particular geographic location and would like to obtain information such as the platinum value, gold value, bathymetry, etc., he or she can select any data for that location and look up the related classes. The geodatabase would then show all the related information available from that particular location. These relationship classes can have three types of cardinality: one to one, one to many and many to one relationships. There are eight relationship classes in the Goodnews Bay geodatabase.

Geology Alaska Description

“GeoAK_Desc” is a relationship class that connects the table “GeoAKcode” to the polygon feature class “GeologyAK.” The cardinality of this relationship class is one to many. It connects the polygons to the lithologic descriptions.

Inlet Oil Drill Data

“IO_Drill_Data” is a relationship class that connects the point feature class “Platinum” to the table “IO_Drill_Data_Pt.” The cardinality of this relationship class is one to one. It connects the station locations in the platinum data with the drill hole data of platinum in the table.

Platinum and Gold

“Platinum_Gold” is a relationship class that connects the point feature class “Platinum” to the point feature class “Gold.” The cardinality of this relationship class is

one to one. It connects the platinum data with the gold data, if both of these values exist at the same location.

Platinum and Offshore Lease

“Pt_OffshoreLease” is a relationship class that connects the polygon feature class “OffshoreLease” to the point feature class “Platinum.” The cardinality of this relationship class is one to many. It connects all the platinum data within a particular offshore lease boundary.

Platinum and Quadrangle

“Pt_Quadrangle” is a relationship class that connects the polygon feature class “Quadrangle” to the point feature class “Platinum.” The cardinality of this relationship class is one to many. It connects all the platinum data within a particular quadrangle boundary.

Platinum and Topographic Boundary

“Pt_TopoBoundary” is a relationship class that connects the polygon feature class “TopoBoundary” to the point feature class “Platinum.” The cardinality of this relationship class is one to many. It connects all the platinum data within a particular topographic boundary.

Gold and WestGold Drill Data Gold

“WG_Drill_Data_Au” is a relationship class that connects the point feature class “Gold” to the table “WG_Drill_Data_Au.” The cardinality of this relationship class is one to one. It connects all the gold data from WestGold to the corresponding drill hole data.

Platinum and WestGold Drill Data Platinum

“WG_Drill_Data_Pt” is a relationship class that connects the point feature class “Platinum” to the table “WG_Drill_Data_Pt.” The cardinality of this relationship class is one to one. It connects all the platinum data from WestGold to the corresponding drill hole data.

3.3.2.5 Metadata

Metadata is a file of information, usually presented as an XML, TXT or HTML document format. The metadata describe the basic characteristics of the data. They answers questions such as who, what, when, where, why and how relative to the data. GIS files such as the geodatabase are documented using geospatial metadata. The Federal Geographic Data Committee (FGDC) is tasked to develop standards for geospatial metadata.

ArcCatalog 9.0 has an inbuilt metadata editor. The editor complies with the FGDC and International Organization for Standardization (ISO) standards. There are different stylesheets available with the ArcGIS 9.0 metadata editor. In this study a

standard FGDC stylesheet was used to develop the metadata. The metadata are an integral part of data and will follow when the data are moved or copied to a new location (Li, 2005). The standard FGDC stylesheet has seven categories. The seven categories are as follows:

- 1) Identification Information
- 2) Data Quality Information
- 3) Spatial Data Organization Information
- 4) Spatial Reference Information
- 5) Entity and Attribute Information
- 6) Distribution Information
- 7) Metadata Reference Information

The metadata of the Goodnews Bay geodatabase are stored on the CD located in the pocket.

3.4 QUALITY CONTROL/QUALITY ASSURANCE

Several paper maps were converted to GIS vector features (digitized). These conversions involve two steps: registering and digitizing. Registering is the process of associating geographic references to the paper map using control points, and digitizing is the process of converting the raster cells of the paper map to vector features. The different measures that were adopted to ensure that the error built-in by these processes was minimized and was within the specified standards are discussed below.

For the purpose of registering, six to ten definite locations were identified and these points were selected as control points. A second order polynomial transformation was used to move the paper map from non-real world space to a real world space (geographic coordinates). Root Mean Square (RMS) error was established as the quality check of the transformation. The RMS error is an average deviation of the distance between the transformation of each input control point and the corresponding point in the map coordinates. In all the cases, the RMS error was kept less than 0.004 digitizer inches, which is the ESRI standard for highly accurate data (Booth et al., 2002).

All the digitizing was done by interactive vectorization using the standard editor sketch tools or the ArcScan vectorization trace tool. In order to improve the accuracy of the interactive vectorization it was always carried out in conjunction with raster snapping, as recommended by Sanchez (2002). However, there could be some errors in the geographic location of the data, due to the variation in the accuracy of the position systems used and inherent errors in the original paper maps.

After the geodatabase was developed and tested, the next step was to analyze the information collated in the geodatabase to assess the need for more data collection in order to verify the hypotheses.

4.0 EXPLORATION OF THE GEODATABASE AND FIELD DATA COLLECTION

The primary assessment made after the development of the geodatabase was whether the data and information available were adequate to meet the objectives of this study. In order to explore this question, two important datasets in the geodatabase were analyzed. These datasets were the geophysical explorations and the precious metal explorations.

4.1 GEOPHYSICAL EXPLORATIONS

The study of the available geophysical data in the Goodnews Bay geodatabase revealed that both the magnetic surveys carried out by USBM and WestGold indicated the possible presence of drowned ultramafic rocks (**Figure 4.1**). The drowned ultramafics recognized by the USBM were identified clearly in the nearshore area by closely spaced transects; however, those identified in the offshore were interpreted from widely spaced transects and needed more investigation (Barker and Lamal, 1989). In addition, the possible drowned ultramafics recognized by WestGold in the south as south-west lobes lacked clear documentation. The only documentation available on these data was a map showing the possible extent of drowned ultramafics. It was indicated as being based upon WestGold geophysical data, and was presented in a report prepared by Howkins (1988). These data warranted an additional magnetic survey offshore of Goodnews Bay, to establish the presence of drowned ultramafic rocks.

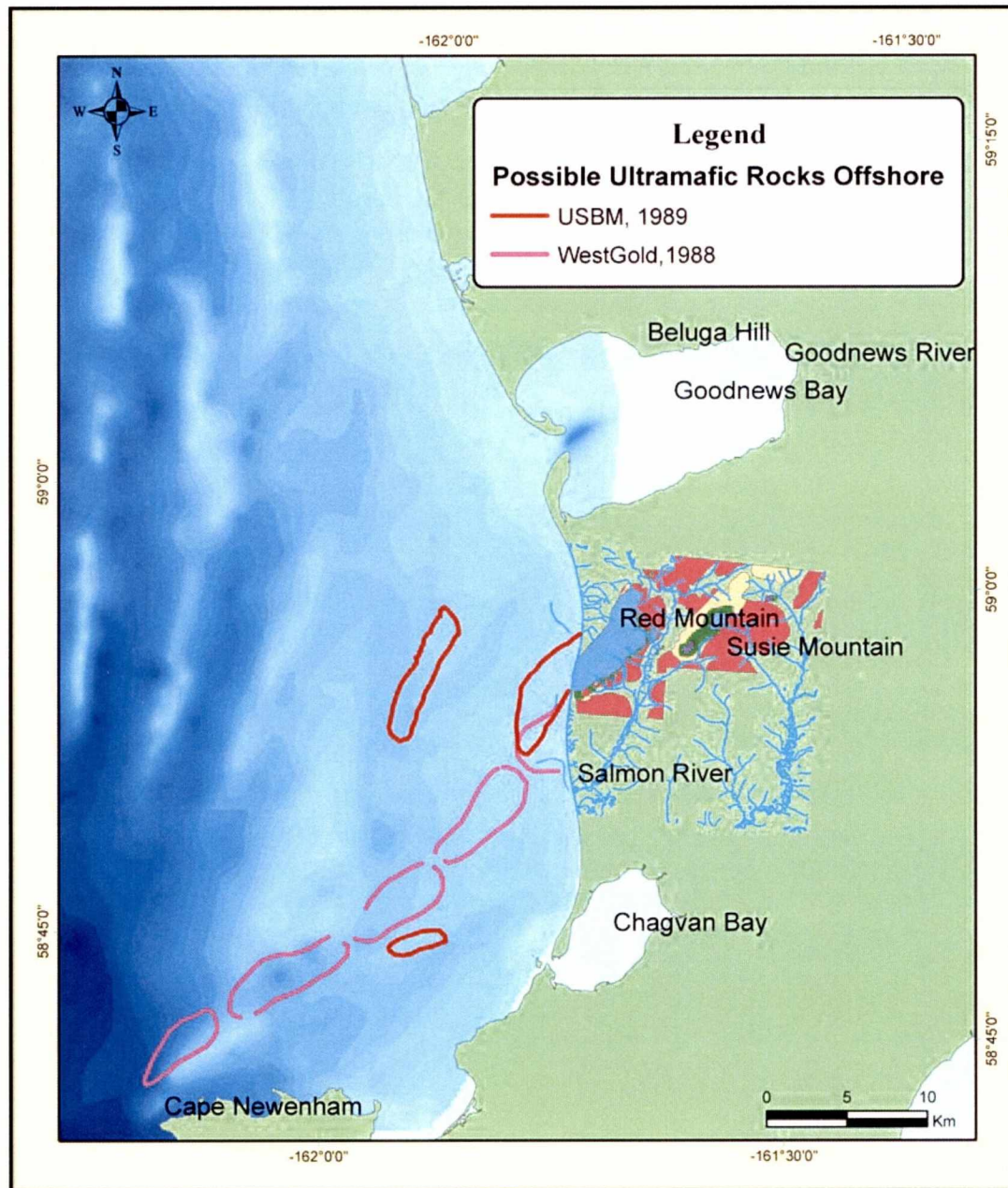


Figure 4.1: Possible drowned ultramafic rocks, identified from geophysical survey by WestGold in 1988 and U. S Bureau of Mines in 1989. Literature suggests that these have been identified from limited data and need further investigation.

The other data analyzed offshore were the seismic data. The only available seismic data interpretation was from the work of Zelenka (1988), which revealed submerged paleochannels (**Figure 4.2**). These seismic data were collected by Barnes in 1969 for the USGS and interpreted by Zelenka in 1988 (Barnes, 1986; Zelenka, 1988). However, it was documented by Zelenka (1988) that these channels were identified using limited seismic data, that their locations were approximate, and that more investigation was required to precisely define their locations.

From the above analysis, it was recognized that there was a significant need to collect more geophysical data from the offshore region of Goodnews Bay to conclusively define the location of drowned ultramafic rocks and the buried paleochannels. If these locations could be precisely defined, the proximal areas to the drowned ultramafic rocks and the buried channels draining these rocks would be the ideal locations for rich buried deposits of placer platinum analogous to the onshore placer platinum deposits.

4.2 PRECIOUS METAL EXPLORATIONS

After studying the geophysical data, the next dataset that was evaluated from the geodatabase was the precious metal dataset. These data are needed for the resource assessment. The geodatabase had 428 data points (locations denoting platinum value) from four different sources. The different sources that contributed platinum data were the USGS, the Inlet Oil Corporation, the USBM and WestGold. The sample locations obtained from these organizations are given in **Figure 4.3**.

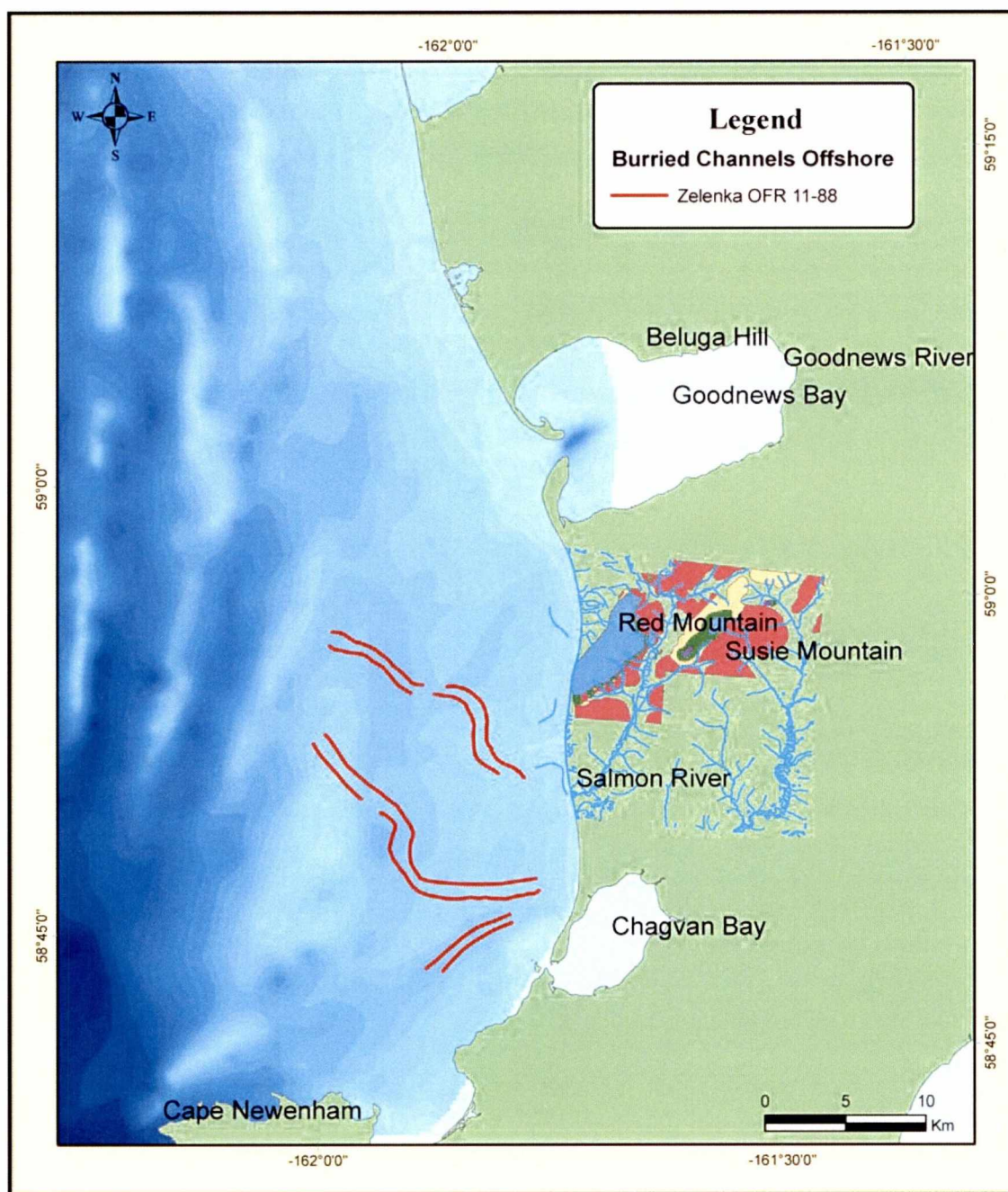


Figure 4.2: Buried channels in the study area as interpreted by Zelenka (1988). These channels were interpreted from limited seismic data collected by Barnes in 1969 for USGS. If these channels are the major drainages in the offshore for the buried ultramafic rocks, then these channels definitely could be rich buried deposits of placer platinum, analogous to the Salmon River valley.

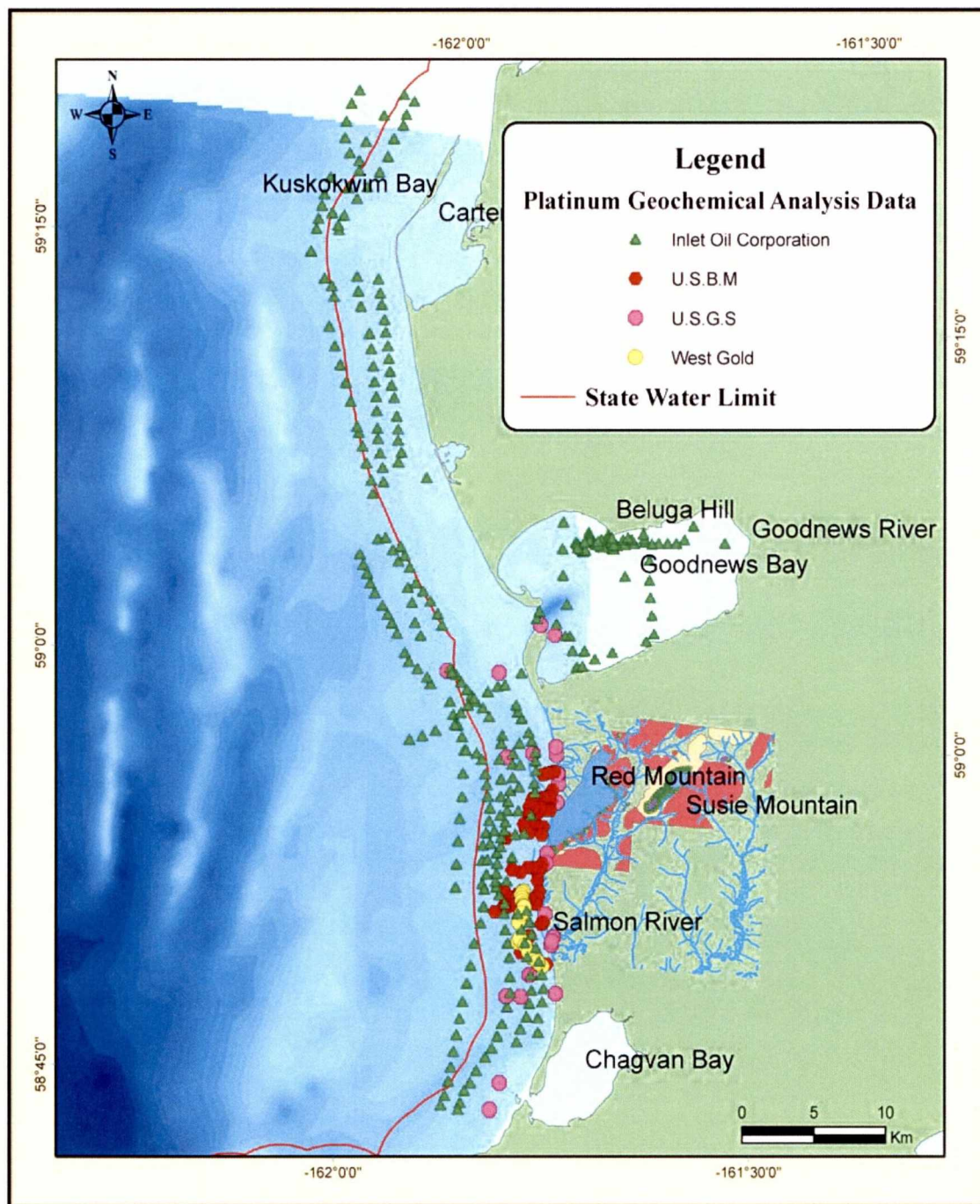


Figure 4.3: Sample locations for platinum, collected by various organizations in the study area. It is observed from this figure that most of the data collected in the past has been from state water limits. There are very few data from federal waters.

However, the integration of the platinum data from these different organizations into the geodatabase and their investigation revealed that most of the platinum data from this region were within the 4.8 km limits (state waters) and that there were very few data available from the far offshore regions (federal waters). It was also observed (**Figure 4.3**) that there were no data collected near buried sand bars which could verify the possibility of accumulating lag deposits of heavy minerals during the marine transgressive cycles. Therefore, in order to test the hypothesis on sand bars, data needed to be collected from these far offshore regions.

The analysis of both the geophysical exploration and precious metal data in the geodatabase suggested the need for more data collection to define and assess the resource potential of platinum in this region. Therefore, a research cruise was planned in the summer of 2005 to collect more data and to populate the geodatabase with the missing information for the resource assessment of platinum in the study area.

4.3 “PLATINUM CRUISE 05”

The research cruise that was carried out in the summer of 2005 was named “Platinum Cruise 05,” because the principal mineral under investigation in this cruise was platinum. The vessel used for the cruise was the M/S Erin Lynn, which is shown in Appendix A.1. The members of the cruise and their affiliations are given in Appendix A.2. Both geophysical data collection and sediment sampling were carried out as part of the cruise. The support for the geophysical survey was provided by the Golder Associates

Inc., Washington, while the Inner Space Exploration Team, Washington, provided the support for sediment sample collection.

4.3.1 Geophysical Survey

The specific activities of the geophysical survey included a magnetic survey to identify magnetic anomalies, a seismic survey to determine the structural geology and a side scan sonar survey for surficial sediment mapping. The geophysical survey was mostly concentrated in the offshore regions of Goodnews Bay, where more precise data were required to define the magnetic anomalies and buried channels as discussed in Section 4.1.

Within this area, four geophysical transects were run in a north-south orientation as shown in **Figure 4.4**. On all the four transects, the specific geophysical activities were run simultaneously. **Figure 4.5** is an illustration of the combined operation of all the geophysical activities and the positioning of the instrumentation on the vessel. The survey transect lines were preplanned, considering the data requirements, as guided by the geodatabase. The vessel was navigated along the preplanned transects using a CSI ProMax Differential Global Positioning System (DGPS). The DGPS provided sub-meter accuracy and was interfaced with the geophysical digital acquisition systems in order to archive the data with position information. The speed of the vessel was maintained between 2.5 and 3.5 knots. The instrumentation used for the specific activities is explained below:

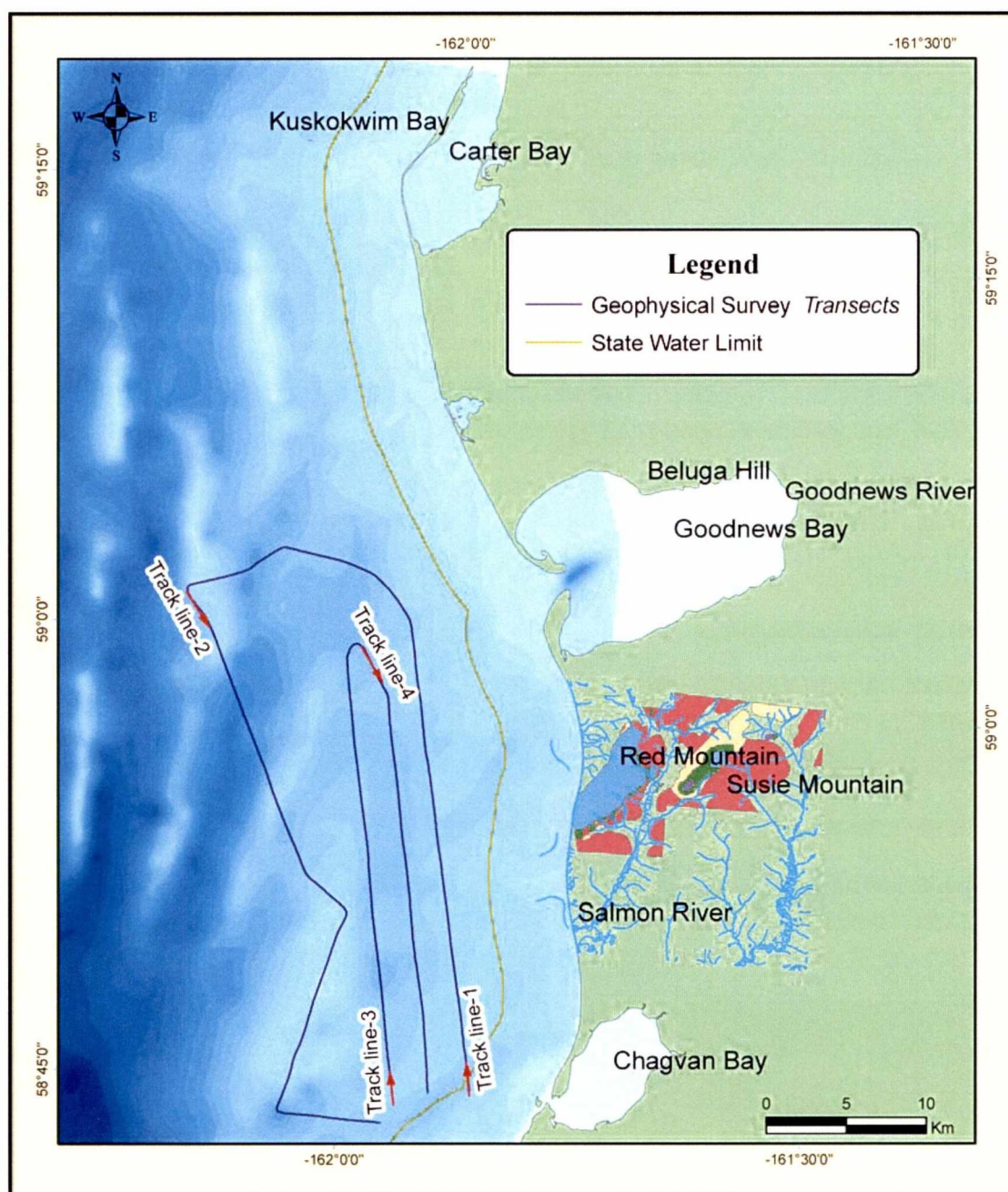


Figure 4.4: Transect lines used for the geophysical survey, which was carried out within the study area at Goodnews Bay in Southwest Alaska. This study was carried out in the summer of 2005. The principal mineral under investigation was platinum; hence the cruise was called “Platinum Cruise 05.”

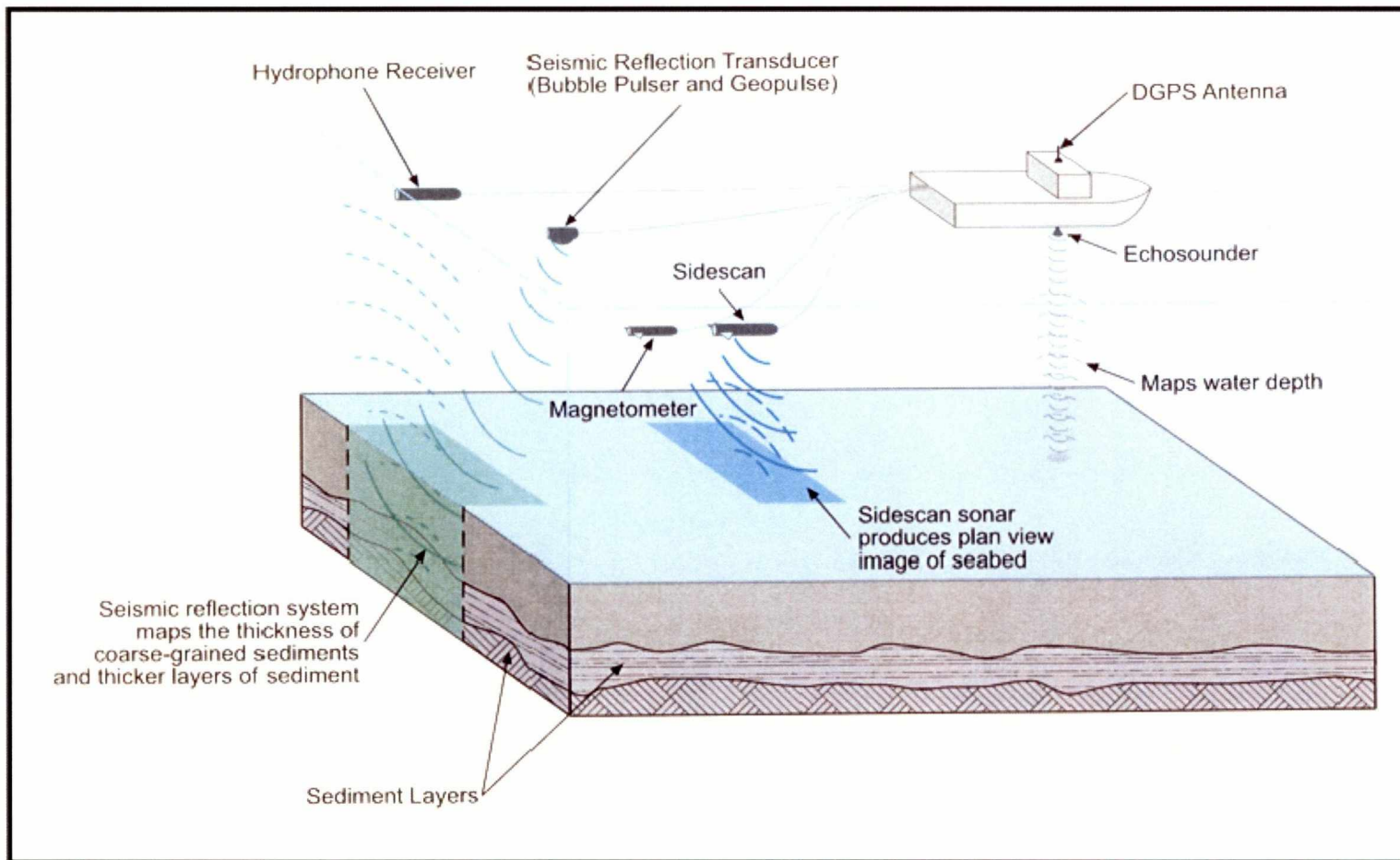


Figure 4.5: An illustration of the geophysical instruments and their operational position along the transect lines during “Platinum Cruise 05.” The specific geophysical measurements like magnetics, seismic and sidescan sonar were done simultaneously along the four transects. (Source: Golder Associates, Washington).

4.3.1.1 Magnetic Survey

The magnetic data were acquired using a SeaSpy marine magnetometer (Appendix-A.3). The magnetometer produced a graphic record and stored the data in digital format. It worked on the principle of nuclear magnetic resonance technology, which is applied specifically to hydrogen nuclei. The output of the instrument is a measurement of the ambient magnetic field. The SeaSpy marine magnetometer has a very high sensitivity, delivering high-resolution output with a noise level of 0.01nT/Hz and counter sensitivity of 0.001nT. In order to minimize the influence of the survey vessel's hull, the magnetometer was towed at a distance of 2.5 to 3 times the length of the vessel.

4.3.1.2 Seismic Survey

The seismic survey data were acquired by continuous subsurface reflection profiling using acoustic pulses. These were emitted at regular intervals by an energy source (transducer) and their reflections received by the hydrophones as shown in **Figure 4.5**. There were two high resolution seismic reflection systems. One was the Datasonic Bubble pulser, which is a low frequency (350 to 800 Hz), deep penetration system and the other is an Applied Acoustic Engineering Model 500 (Geopulse), which is a high frequency (750Hz to 2 KHz) shallow penetration system (Appendix-A.4). The acquired data were displayed in real-time on an EPC Model 1086 thermal graphic recorder and digitally stored on a Sony PC208 DAT recorder and DSP digital acquisition system.

4.3.1.3 Sidescan Sonar

The sidescan sonar instrument was used to map the surficial characteristics of the seabed, operated at 100 KHz on a 160m swath width. The data were acquired with a GeoAcoustic dual frequency (500 and 100 KHz) sidescan system and were displayed real time on a graphic recorder and archived on a digital acquisition system.

4.3.2 Sediment Sample Collection

The different devices that were used to obtain sediment samples from the study area were a Van Veen Sampler, Pipe Dredge and Vibracore. A total of 49 samples were obtained, out of which 2 samples were collected inside the Goodnews Bay and the rest were from the offshore (outside the 4.8 km limit). The sample locations and the sample IDs are shown in **Figure 4.6**.

4.3.2.1 The Van Veen Sampler

The van veen is a grab sampling device and is shown in Appendix-A.5. Inside Goodnews Bay, several attempts were made to obtain a representative sample using the van veen sampler. However, all the attempts failed either because the material was too coarse-grained for sampling or rocks in the sample would prevent the jaws of the sampler from closing, which in turn would cause the fine to medium-grained material to be washed out before the sampler could be retrieved from the seabed. Therefore, no samples were recovered using the van veen sampler.

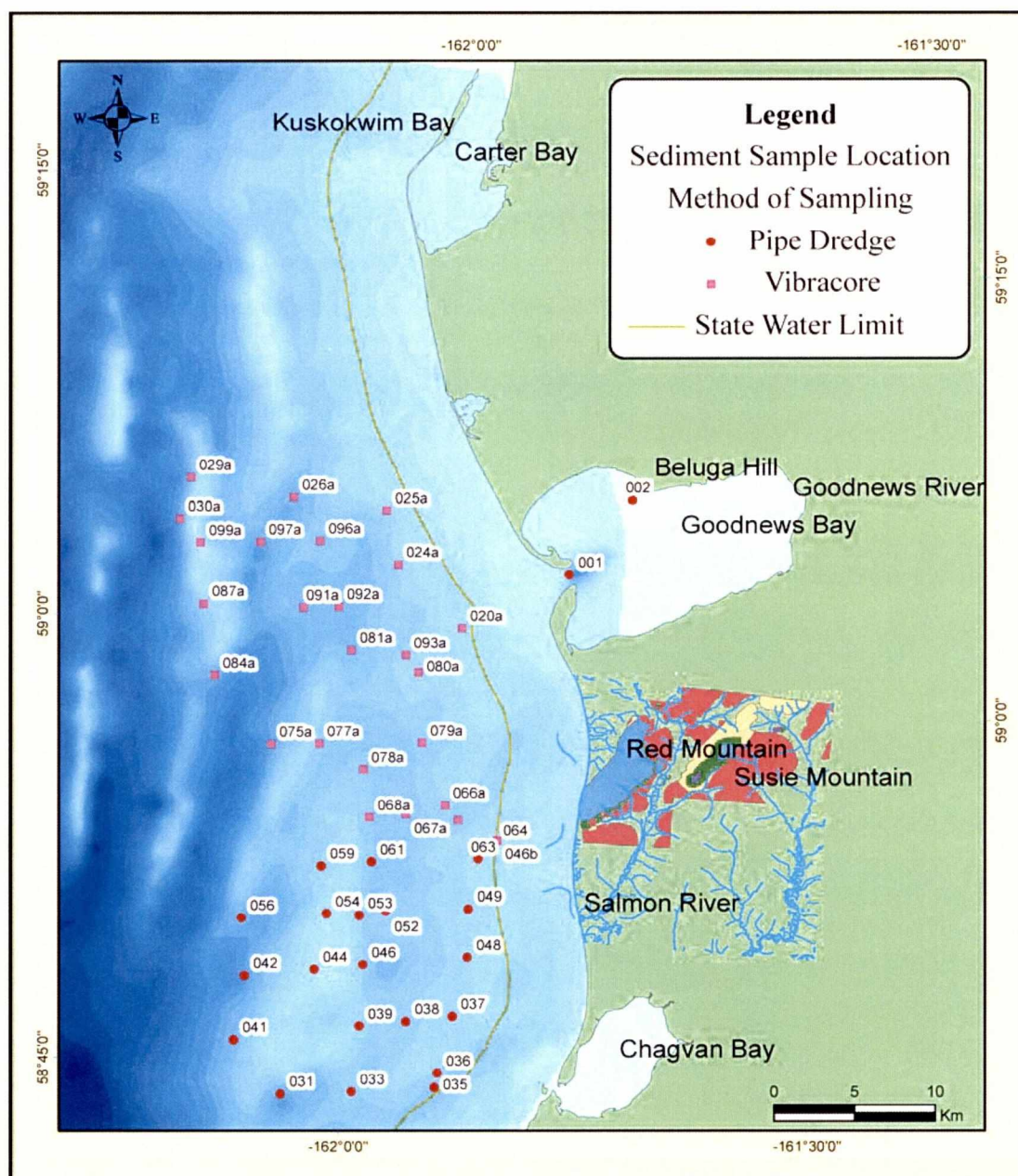


Figure 4.6: Location of the 49 samples from "Platinum Cruise 05." The 23 pipe dredge samples and the 26 vibracore samples are differentiated by circles and squares. Out of the 49 samples, 2 are within state water limits in the bay area, and the rest are in federal waters.

4.3.2.2 Pipe Dredge

A Pipe dredge is also a grab sampling device. A pipe dredge of 30cm diameter was used as the sampler in the study area, as shown in Appendix-A.6. At the selected locations, the sampler was lowered to the seabed and then allowed to be dragged for 3 to 5 minutes as the vessel drifted with wind or current before the sampler was retrieved. The sampling using pipe dredge was successful, and 23 samples were collected using this method. However, the disadvantage was that after lowering the pipe dredge to the seabed, there was a wait of 3-5 minutes for the sampler to fill. This filling was achieved by the sampler getting dragged on the seabed due to the drift of the vessel, caused by wind or current. For this reason, determination of the exact location of the sample was difficult. In this study the location of the pipe dredge just before the sampler was retrieved from the seabed was documented. The pipe dredge samples were transferred to plastic buckets in order to be transported to Fairbanks, Alaska for further analysis.

4.3.2.3 Vibracore

A vibracore is a vibratory coring device, having a 4-inch diameter barrel, which is 3m long. It has a NWGS 3HP motor, used for providing the required vibration to penetrate the core into the seabed. A guide mechanism was used to make sure that the barrel was not inclined and penetrated straight into the seabed. A metallic core catcher was used to retain the penetrated material in the barrel. The details of the vibracore are given in Appendix-A.7. The vibracore was successfully used to collect 26 samples. The

depth of penetration varied from 1 to 3m into the sea bed. The extra length of the barrel was trimmed, and samples were sealed inside the barrel for further analysis.

After the sediment samples were collected, the next step was to analyze the samples for platinum.

4.4 SEDIMENT SAMPLE ANALYSIS

One of the most challenging steps in resource estimation of precious minerals is the geochemical analysis of the sediment samples. Moore (1972) stated that “platinum amounts that would be of economic interest in marine sediments could be very easily missed if one followed the so-called standard methods in literature.” Studies were carried out by Moore to assess different analytical techniques for the analysis of marine samples (Moore 1972). However, there has not been an optimal method established for the analysis of precious minerals so far. In the case of samples collected in 2005 (“Platinum Cruise 05”) a three stage sediment analysis technique was adopted, similar to the analysis conducted by USBM in 1988 (Barker et al., 1988). The three different stages involved in this analysis are the preparation stage, heavy mineral separation and fire assay.

4.4.1 Preparation Stage

The preparation of the samples was conducted at the School of Fisheries and Ocean Sciences (SFOS) and Mineral Industry Research Lab (MIRL), UAF. The different steps of the preparation stage are explained briefly as a flowchart (**Figure 4.7**). Photographs of some of these steps are provided in Appendix-B. The objective of the

preparation stage was to obtain a representative sample of 750grams which was free of clay ($<4\mu\text{m}$) and coarse particles of size greater than a No. 20 ASTM-E11 sieve, so that the sample was ready for heavy mineral separation.

4.4.2 Heavy Mineral Separation

The heavy mineral separation was carried out by Overburden Drilling Management Limited, Ontario, Canada. The objective of the heavy mineral separation was to separate the heavy mineral concentrate for fire assay from the 750gram sample obtained from the preparation stage. The heavy mineral concentrate was separated from the sample using methylene iodide (specific gravity = 3.2). The separated heavy mineral fraction was further processed by fire assay.

4.4.3 Fire Assay

The fire assay work was executed at ALS Chemex, Vancouver, Canada. The procedure included fusion and preparation of the sample for Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES). A 30 – 50 gm sub-sample of the heavy mineral concentrate was fused with a mixture of lead oxide, sodium carbonate, borax and silica, inquarted with 6 mg of gold-free silver and then cupelled to yield a precious metal bead. The bead was then digested for 2 minutes in dilute nitric acid using a microwave oven. The solution was cooled and hydrochloric acid was added. The solution was digested for an additional 2 minutes at half power in the microwave oven. The digested solution was

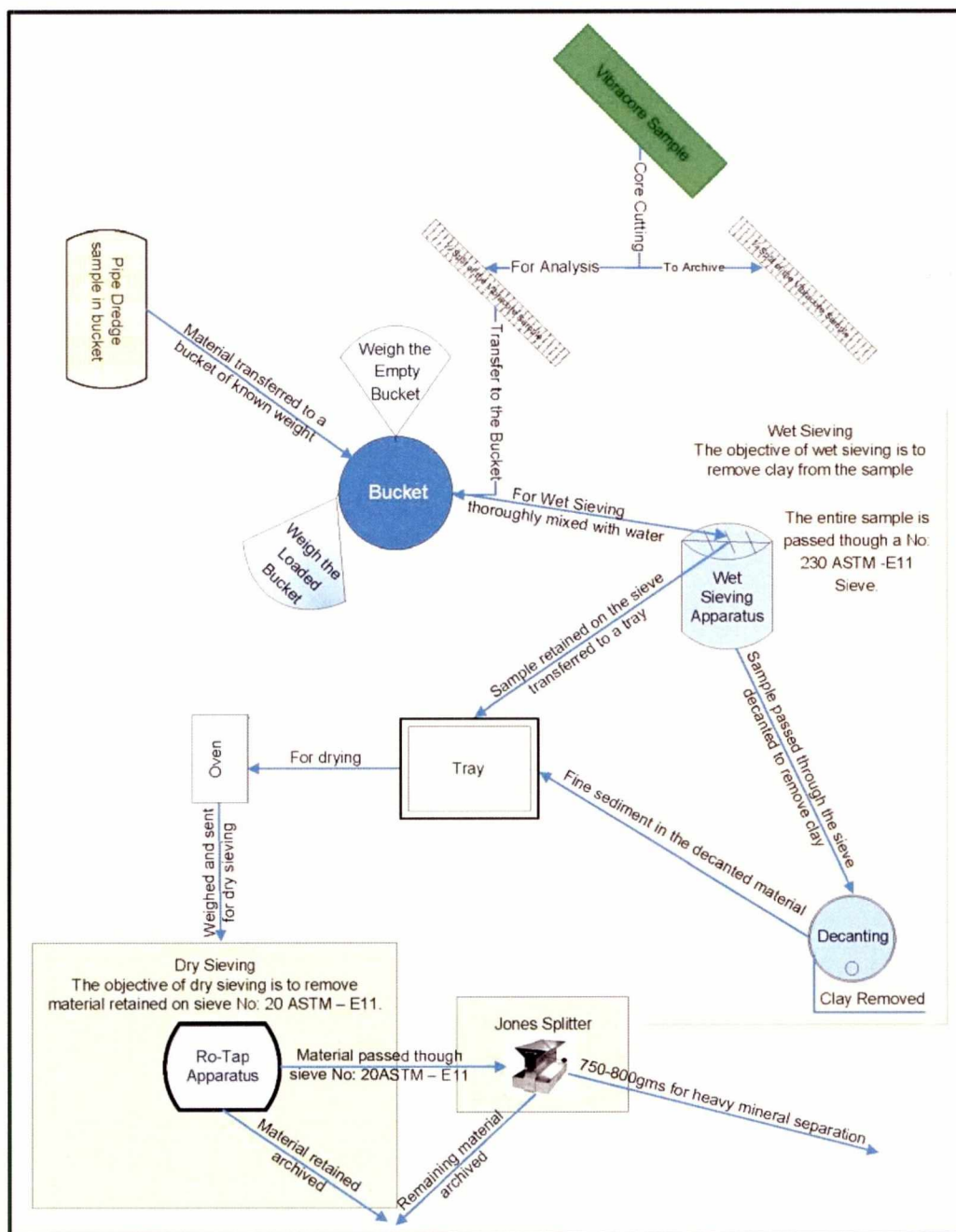


Figure 4.7: Flowchart illustrating the different steps involved in the preparation stage. The preparation stage is the process in which a representative sample of (750-800gm) is developed for heavy mineral separation.

then cooled, diluted to 4 mL with 2 % hydrochloric acid, homogenized, and finally analyzed for gold, platinum and palladium by ICP-AES (ALS Chemex, 2005). The lower limits of detection for gold, platinum and palladium were 0.001, 0.005 and 0.001ppm, respectively (ALS Chemex, 2005).

The results of gold, platinum and palladium concentrations in the fire assay were obtained in both ppm and oz/ton ($0.1\text{ppm} = 0.00292\text{ oz/ton}$).

Since these concentrations represented the amount of the mineral in the heavy mineral concentrate, they were recalculated for the entire sample. Recalculated results representing the value of the mineral for the entire sample at a particular location were integrated into the geodatabase which is stored on the CD in the pocket. After the development of the geodatabase and the integration of the data were complete, the data in the geodatabase were analyzed to verify the research hypothesis and achieve the objectives of this research.

5.0 DATA ANALYSIS

5.1 ANALYSIS

The data integrated into the Goodnews Bay geodatabase were further analyzed to assess the agents, modes and the extent of transport and deposition of platinum. This analysis was carried out in three phases. The first phase was to analyze the geophysical data collected during “Platinum Cruise 05” and compare them with those collected in past studies to identify the location of ultramafic rock and paleochannels in the marine environment. The second phase was the characterization of the satellite imagery to determine the influence of the coastal current on the sediment distribution pattern in the study area and to determine whether the sediment distribution pattern has any correlation with the distribution of platinum. The third phase was to explore the platinum values in the geodatabase to model their spatial distribution and establish their association with the source rock, depositional environment and agents.

5.2 GEOPHYSICAL DATA ANALYSIS

As described in Section 4.1 the basic aim of the geophysical survey on board “Platinum Cruise 05” was to supplement the rather rare and uncertain offshore geophysical data available from this region and to develop a baseline for future geophysical explorations. In this section the results of the various geophysical surveys that were done in 2005 are discussed and compared to the earlier surveys. Moreover, the implications of this geophysical data for offshore placer platinum are verified.

5.2.1 Magnetic Data Analysis

The marine magnetic data collected during “Platinum Cruise 05” were analyzed to determine if surficial or subsurface geologic features contain magnetite, which is a heavy mineral often allied with the presence of gold and platinum, or ultramafic structures. The unit of measurement for the magnetic data was gamma (1gamma= 1nT). **Figure 5.1** shows the histogram of the magnetic data obtained from the “Platinum Cruise 05.” The statistics of the data are given in **Table 5.1**. The magnetic data were contoured and interpolated using the method of Nearest Neighbor in ArcGIS 9.1. A magnetic value exceeding ± 500 gamma from the mean (53581 gamma) was symbolized as an anomalous magnetic value in the contour map, as shown in **Figure 5.2**. This was the same procedure USBM carried out for marine magnetic data analysis in this region in 1988 (Barker et al., 1988; Barker et al., 1989). The contour map shows several magnetic anomalies on the near shore transects. Two cross sections (A-A’ and B-B’) were obtained along the anomalous areas, as shown in **Figure 5.3**. It is observed from **Figure 5.3** that these anomalous values ranged up to 2000-3000 gammas. Such high positive magnetic anomalies are usually associated with ultramafic rocks. In support of this observation, Dymen et al. (2005) also had mentioned that magnetic anomalies of that magnitude are usually associated with ultramafic rocks.

Recapping the explanations of the geology and structure of ultramafic rock that was discussed in Section 2.2, past studies have interpreted the Goodnews Bay ultramafic complex to be a large, continuous, sill-like body dipping southeast, and folded and

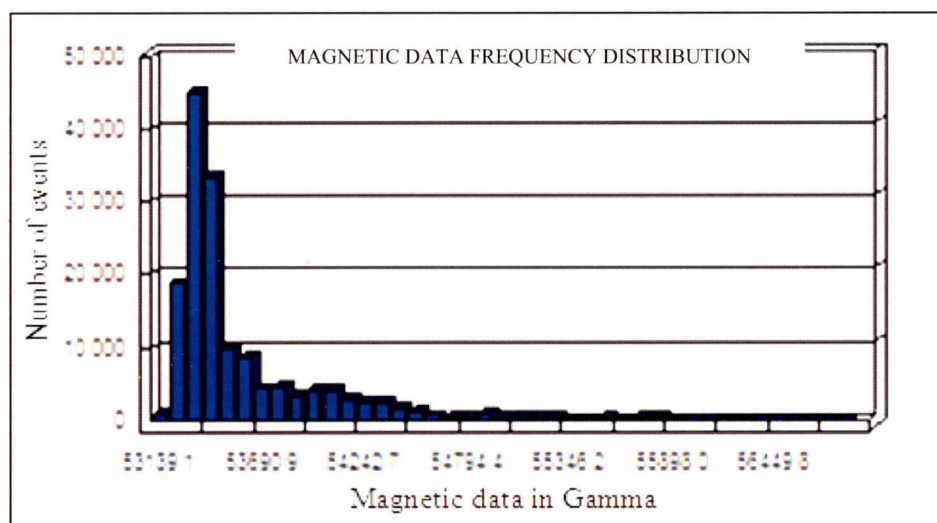


Figure 5.1: Histogram plot for the magnetic data collected using the marine SeaSpy magnetometer during the “Platinum Cruise 05”. Data collection support was provided by Golder Associates Inc, Washington.

Table 5.1: Summary of the magnetic data obtained during the “Platinum Cruise 05”.

Count of Events	149980
Minimum	53100.00 gamma
Maximum	56872.15 gamma
Mean	53581.00 gamma
Standard Deviation	404.68 gamma

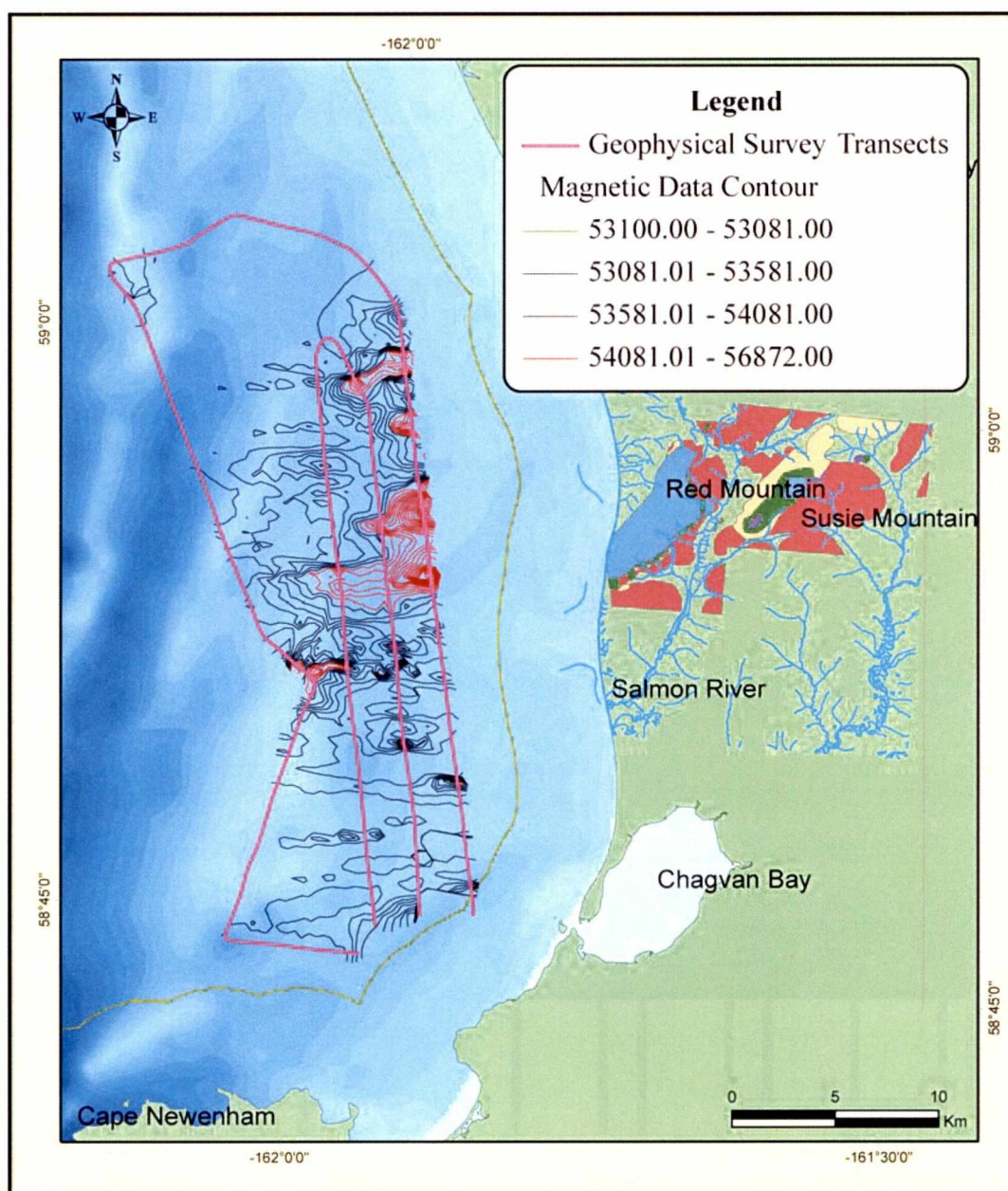


Figure 5.2: Magnetic contours developed using nearest neighbor interpolation in ArcGIS 9.1. The mean of the magnetic data is 53581gamma. The map also shows the four transect lines from the "Platinum Cruise 05."

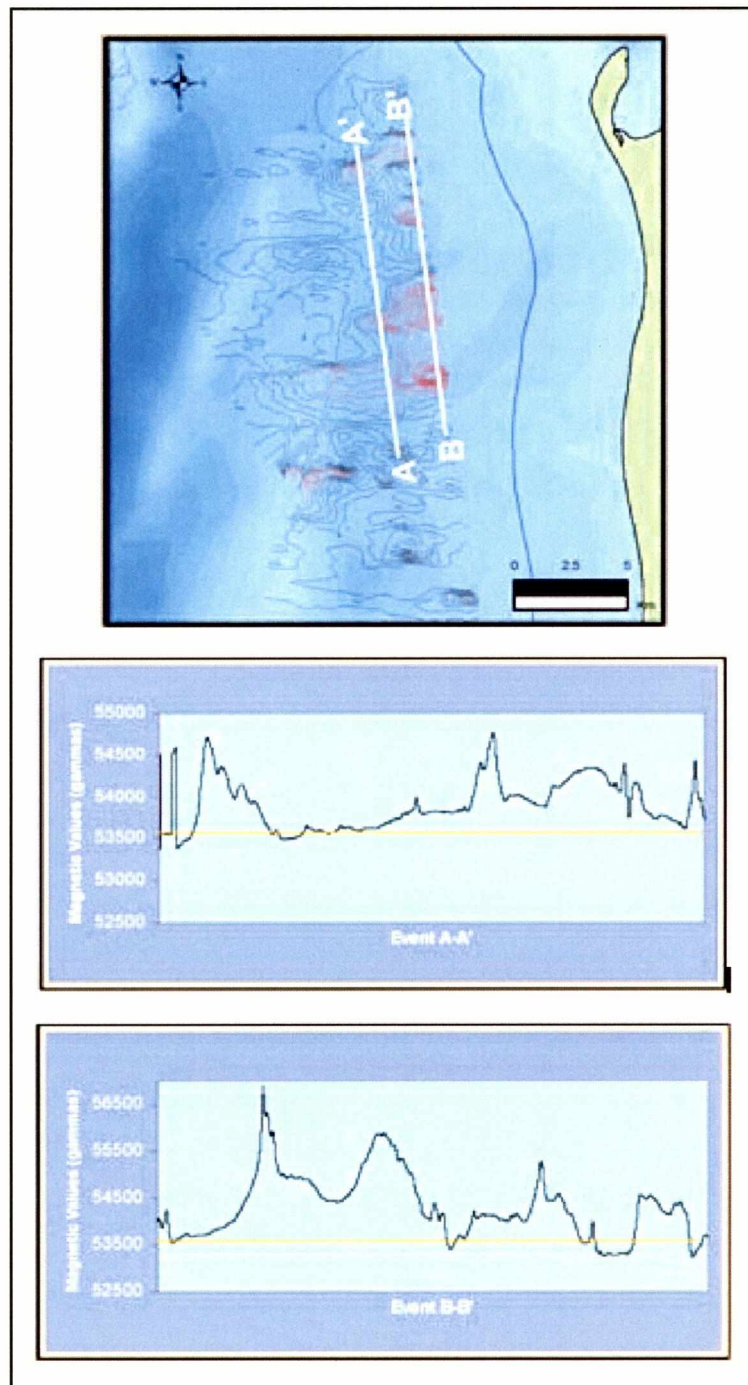


Figure 5.3: Cross section of magnetic contours along lines A-A' and B-B'. It is observed from the cross sections A-A' and B-B' that the magnetic anomalies deviated up to 2000-3000 gammas from the mean magnetism.

faulted at some places (Griscom, 1978; Southworth and Foley, 1986; Southworth, 1986; Barker et al., 1988). **Figure 5.4** shows the magnetic anomalies identified by USBM in the 1988 geophysical survey of this region. The three major findings of the study by USBM are, first, that the magnetic anomalies immediately south of Red Mountain (offshore) observed in **Figure 5.4** are due to an extension of the Goodnews Bay ultramafic complex (Barker et al., 1988; Barker et al., 1989). Secondly, the magnetic anomalies northwest of Red Mountain (**Figure 5.4**) in the offshore are probably displaced by a fault or a convoluted fold similar to that which exists onshore between the Red and Susie mountains (Southworth and Foley, 1986; Barker et al., 1988). Thirdly, the structure of the ultramafic complex northwest of Red Mountain appears to extend farther west beyond the transect lines of 1988 (Barker et al., 1988).

The results of the magnetic data analysis from “Platinum Cruise 05” were studied and compared in light of the geology, structure of the ultramafic rock and the past magnetic surveys in this region. The marine magnetic data observations from USBM were overlaid on the magnetic contours from 2005 data, as shown in **Figure 5.5**. **Figure 5.5** shows that the structure of the ultramafic rock as suggested by USBM extends farther west beyond what was identified in 1988. The magnetic anomalies observed by USBM in the west central (**Figure 5.4**) and the magnetic anomalies from the contoured map (**Figure 5.5**) developed from the 2005 data indicate that an ultramafic structure offshore, similar to that of Red Mountain, exists there. This inferred ultramafic structure offshore

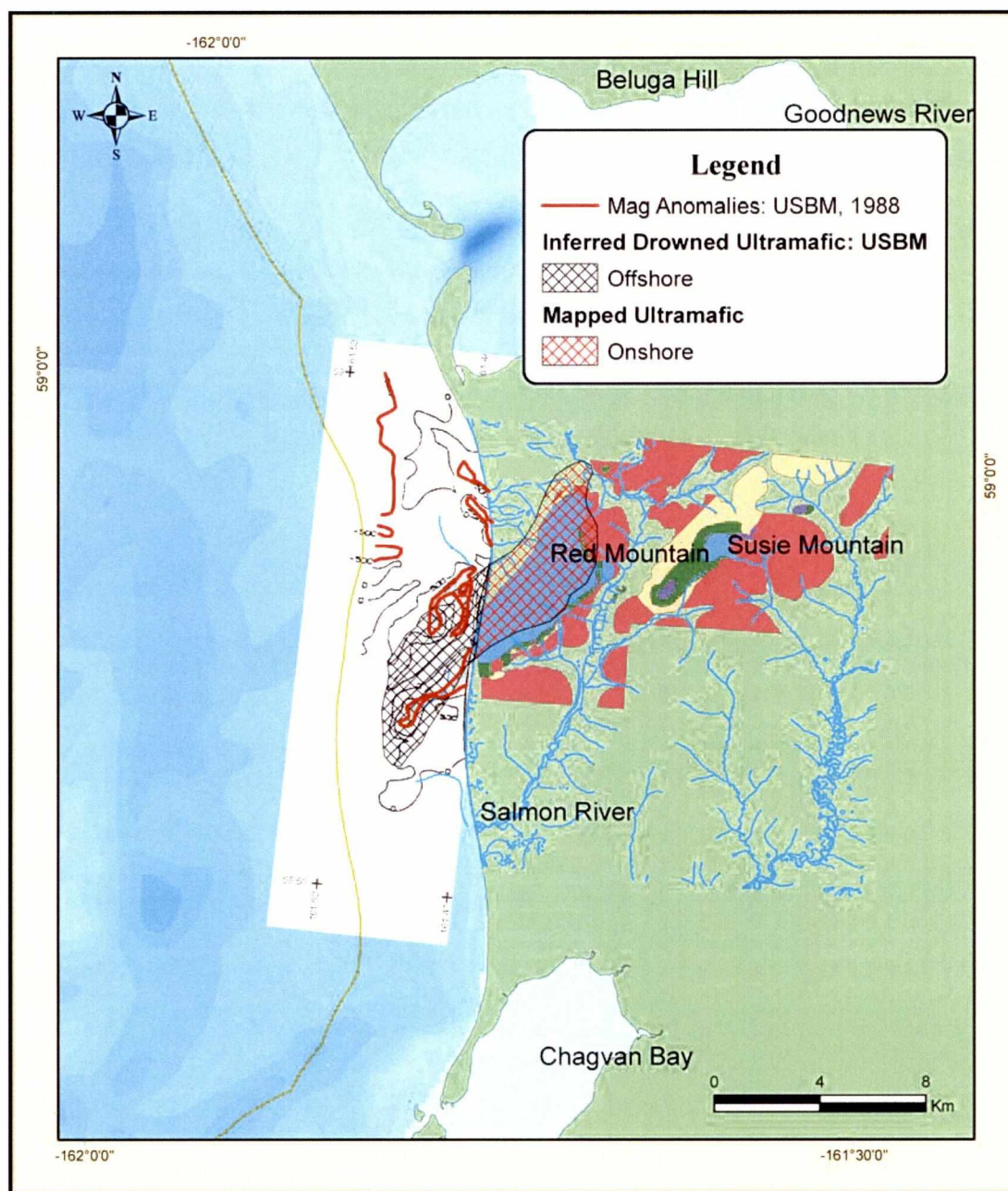


Figure 5.4: Inferred drowned ultramafic rock and the magnetic anomalies offshore from the studies of USBM (Barker et al., 1988). The figure also shows the well mapped ultramafic rock onshore which is considered to be the source rock for platinum mined onshore.

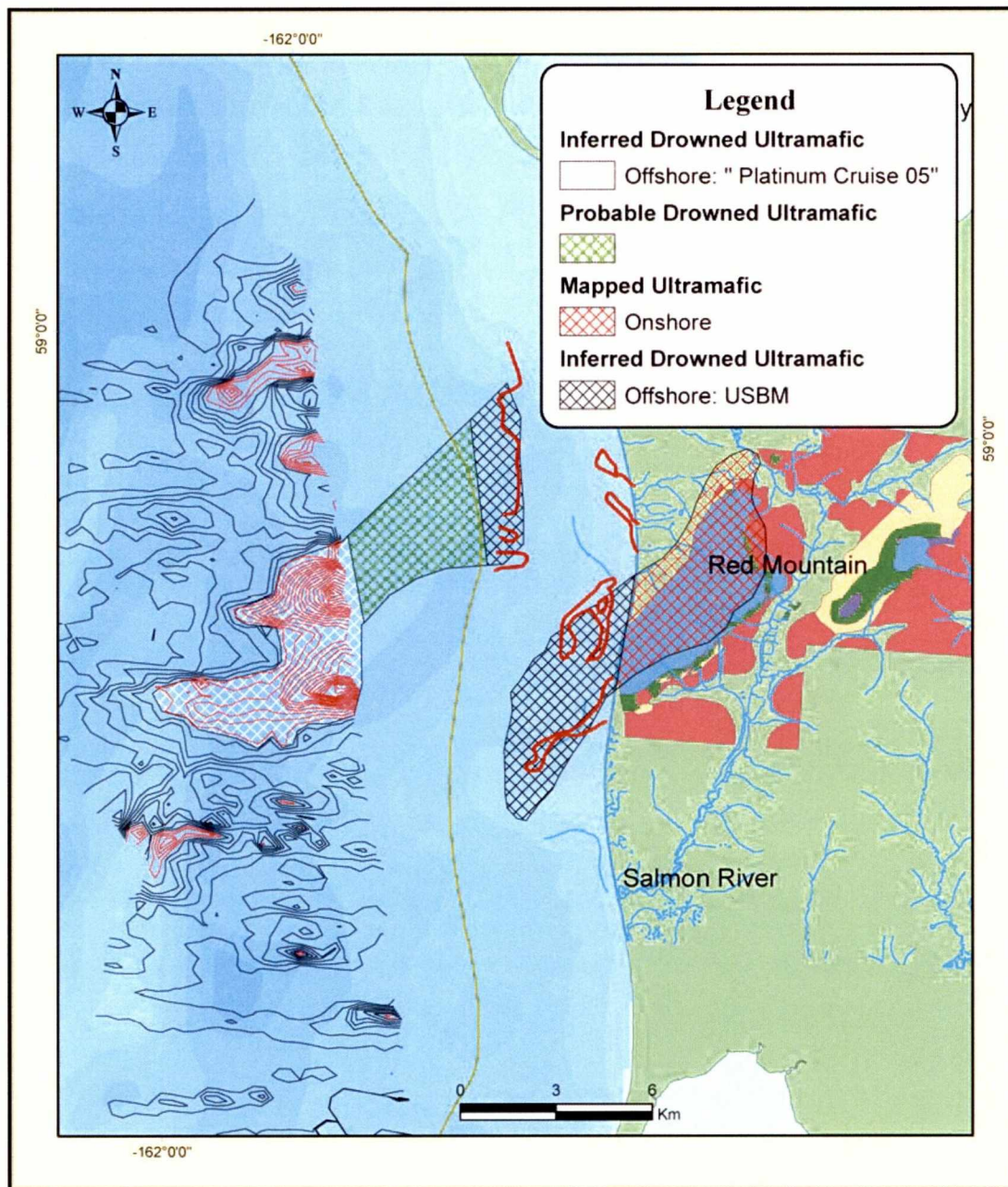


Figure 5.5: Combined analysis of the magnetic data from USBM (Barker and Lamal, 1988) and "Platinum Cruise 05." It shows the positions of mapped, inferred and probable locations of ultramafic rocks both onshore and offshore. It is observed that an ultramafic rock of similar structure that is mapped onshore exists offshore, and areas proximal to this can be potential locations for placer platinum.

is shown in **Figure 5.5**. The boundary for the western face of this structure is clearly defined by the contour map. It is also highly probable that this structure is displaced by a fault, or a convoluted fold, as suggested by Barker et al., 1988.

In conclusion, if an ultramafic structure of similar size to that observed onshore is buried offshore, the areas on and proximal to this could be a rich resource for platinum. The onshore studies identified that the channels that drain the ultramafic rocks were the prospective locations for placer platinum mining. Therefore, if analogous situations existed offshore, channels in the proximity of the ultramafic structure identified offshore would be potential targets for placer platinum. This led to the analysis of the seismic data to map the subsurface geologic features and study the channels in the offshore of Goodnews Bay.

5.2.2 Seismic Data Analysis

The only seismic data available from the offshore region of Goodnews Bay was collected by USGS and published by Zelenka (1988). This study published by Zelenka (1988) had identified three possible buried paleochannels in this region as shown in **Figure 5.6**. However, Zelenka (1988) states that “these channel locations are very approximate and high resolution data is required to verify and define their locations.”

Therefore, the objective of the seismic survey on the “Platinum Cruise 05” was to obtain high resolution seismic data for this region to define the subsurface stratigraphy more accurately. Using the “Platinum Cruise 05” data, a seismic facies and structural

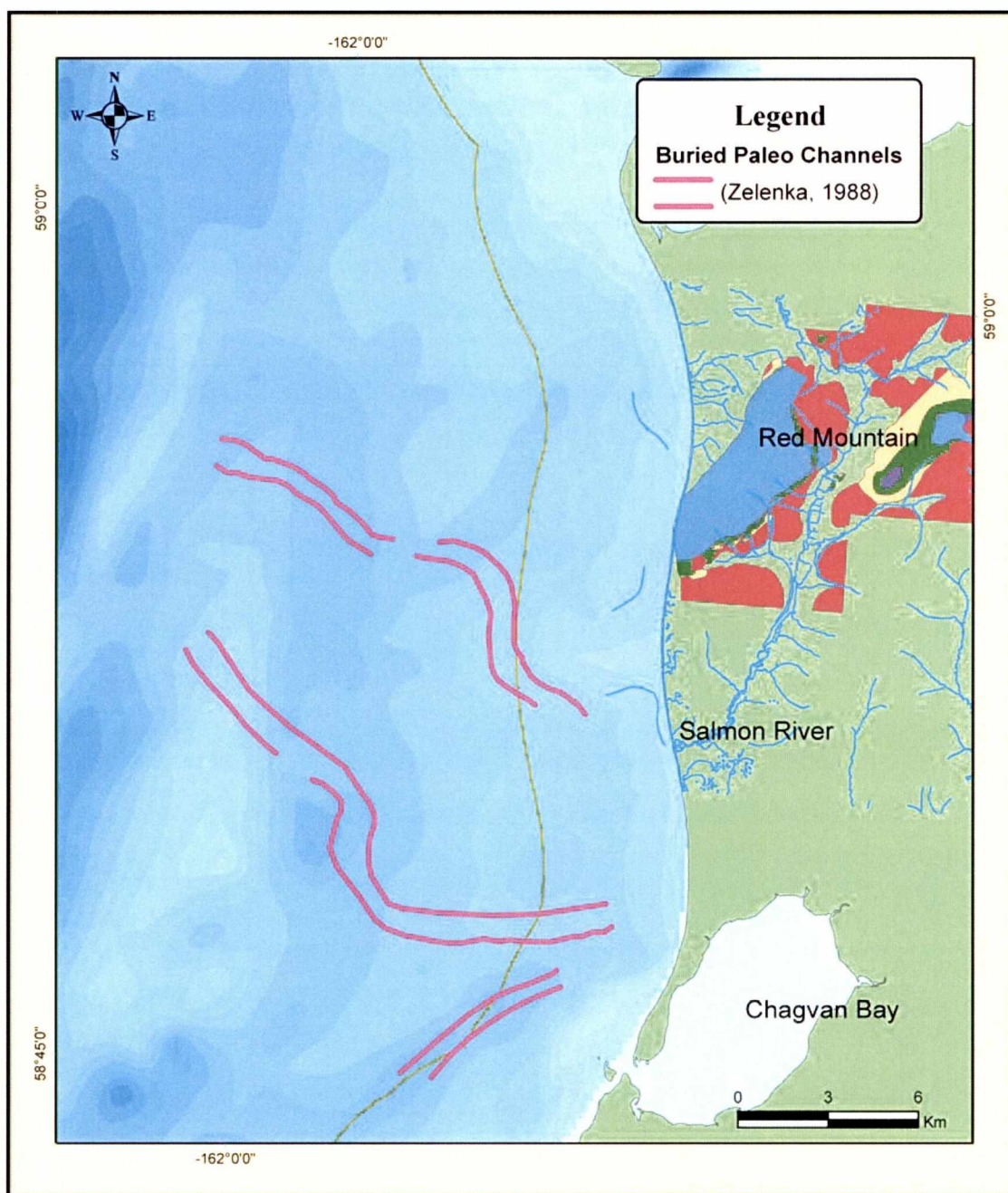


Figure 5.6: Buried paleo-channels identified by USGS and published by Zelenka (1988). This was the only seismic data interpretation from this region prior to “Platinum Cruise 05.”

characteristics map was developed. This map was developed by Golder Associates Inc., Washington and is shown in **Figure 5.7**. Appendix-C provides examples of each of these seismic facies (**Figure 5.7**) that are identified from the seismic reflection data. Analyzing these different seismic facies, a channel was identified in the map to the west of Red Mountain, indicating fine to medium grained channel fill in **Figure 5.7**. In order to verify the position of this channel with respect to the magnetic anomalies identified in **Figure 5.5**, a combined map was developed with the seismic facies and the magnetic data interpretation as shown in **Figure 5.8**. The combined map (**Figure 5.8**) reveals that the channel identified from **Figure 5.7** passed in between the magnetic anomalies (possible buried ultramafic rocks identified in **Figure 5.5**). From the onshore data, it is known that the Salmon River, which was in the proximity of the ultramafic rocks (Red and Susie Mountains), contained all the alluvial placer platinum that was mined. **Figure 5.8** shows an analogous condition to that observed onshore (Salmon River) exists offshore, and the channel identified offshore, being near possible buried ultramafic rock, could be a rich resource for alluvial placer platinum.

Additionally the seismic reflection data were analyzed and showed that the bottom of the channel near the possible ultramafic rock was about 20-40m below the sea bed. A channel was also identified that was not recognized in the seismic facies map; this channel was towards the south of the study area and the seismic reflection data obtained for this channel is shown in **Figure 5.9**. A combined map of all the channels, such as the channel from the seismic facies map, the channel from the seismic reflection data and the

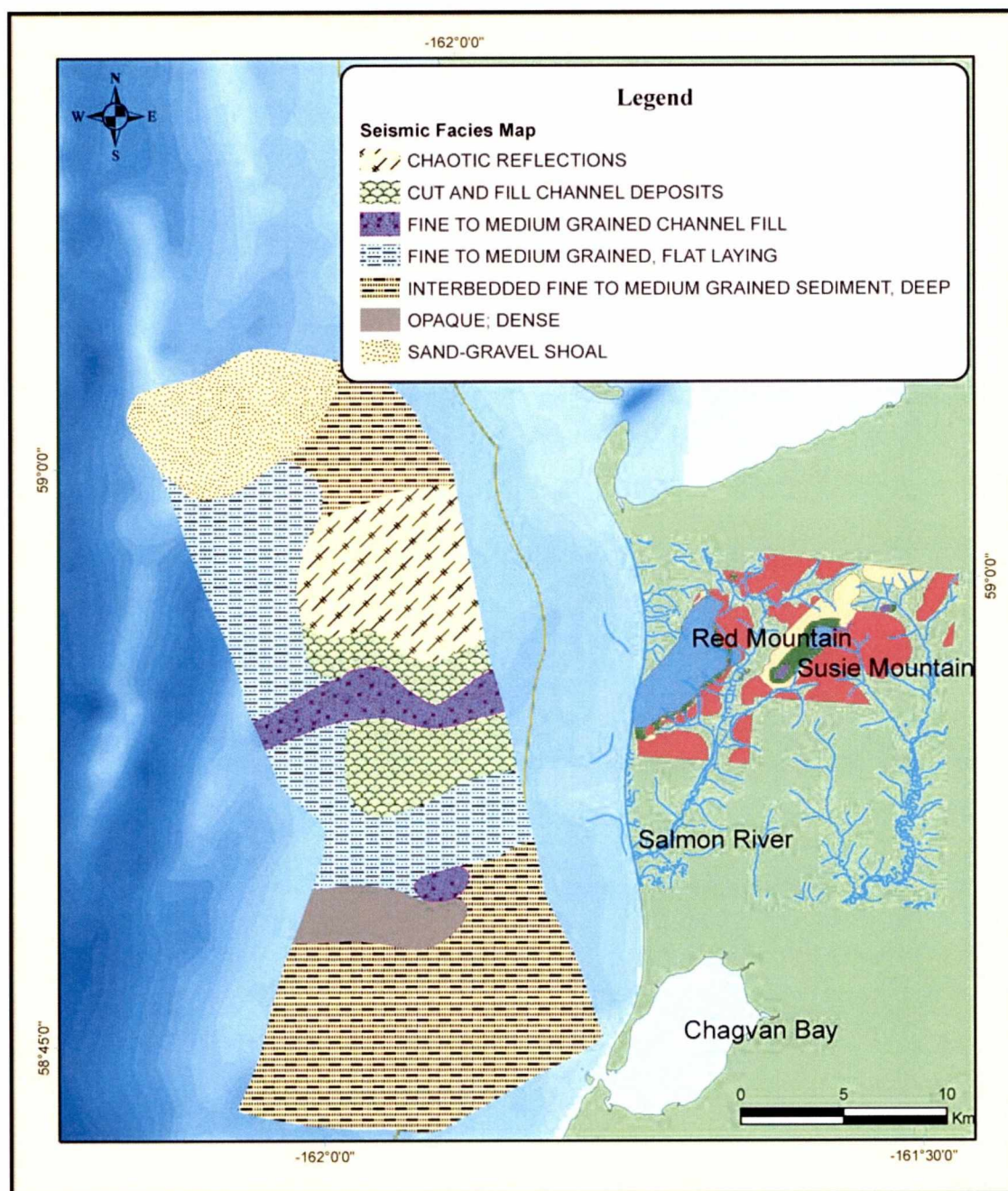


Figure 5.7: Seismic facies map developed from the seismic data collected on the 'Platinum Cruise 0.5'. It clearly identifies a channel west of Red Mountain. This channel is identified as fine to medium grained channel fill in the seismic facies map.

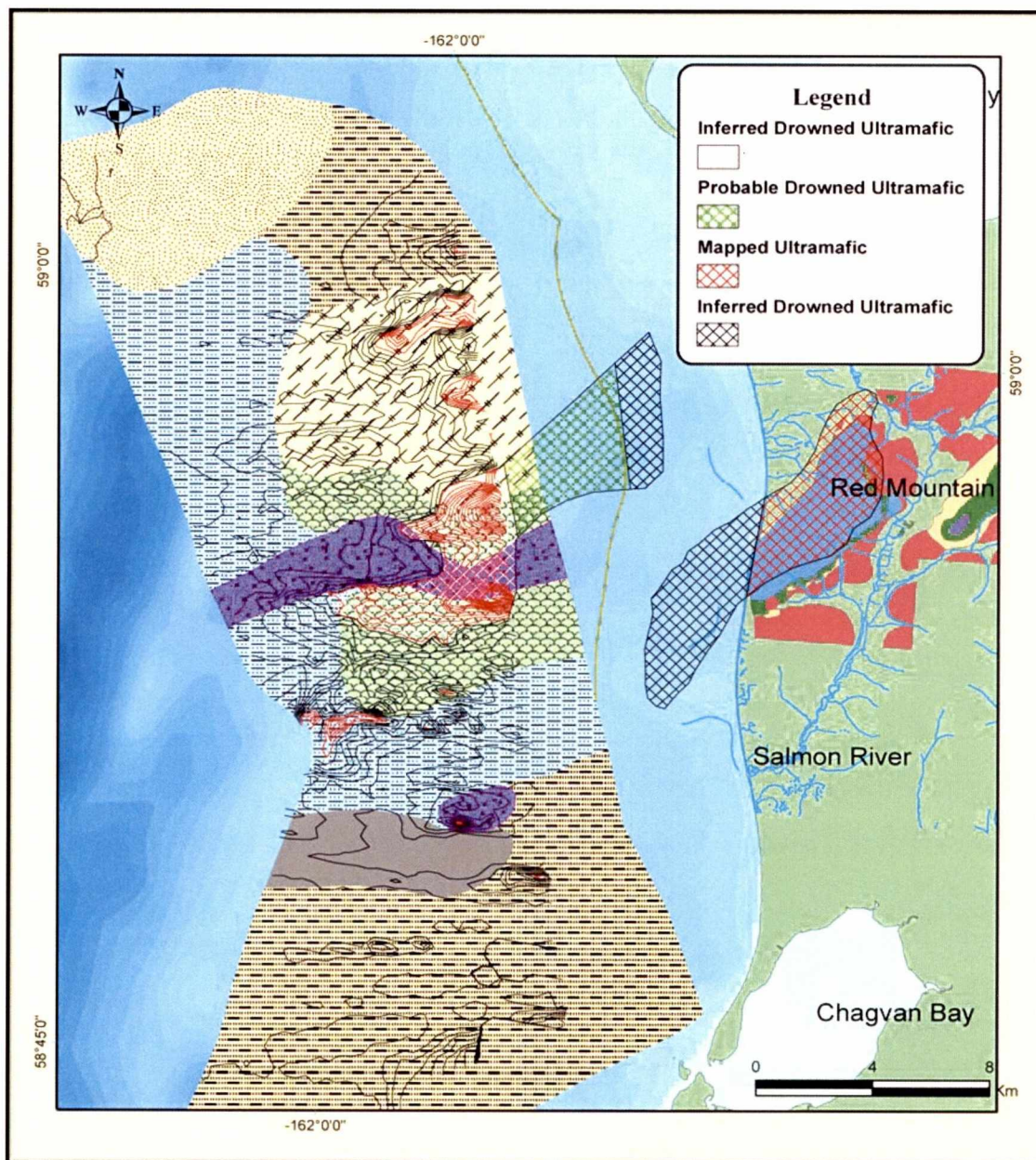


Figure 5.8: A combined map showing the magnetic data interpretation and the seismic facies. It is observed from the above map that the channel identified from the seismic facies map passes between two lobes of magnetic anomalies. This is an indicator that this channel is probably the drainage in the proximity of drowned ultramafic rock. If situations in this channel are analogous to onshore conditions, this channel can be a rich resource for alluvial placer platinum.

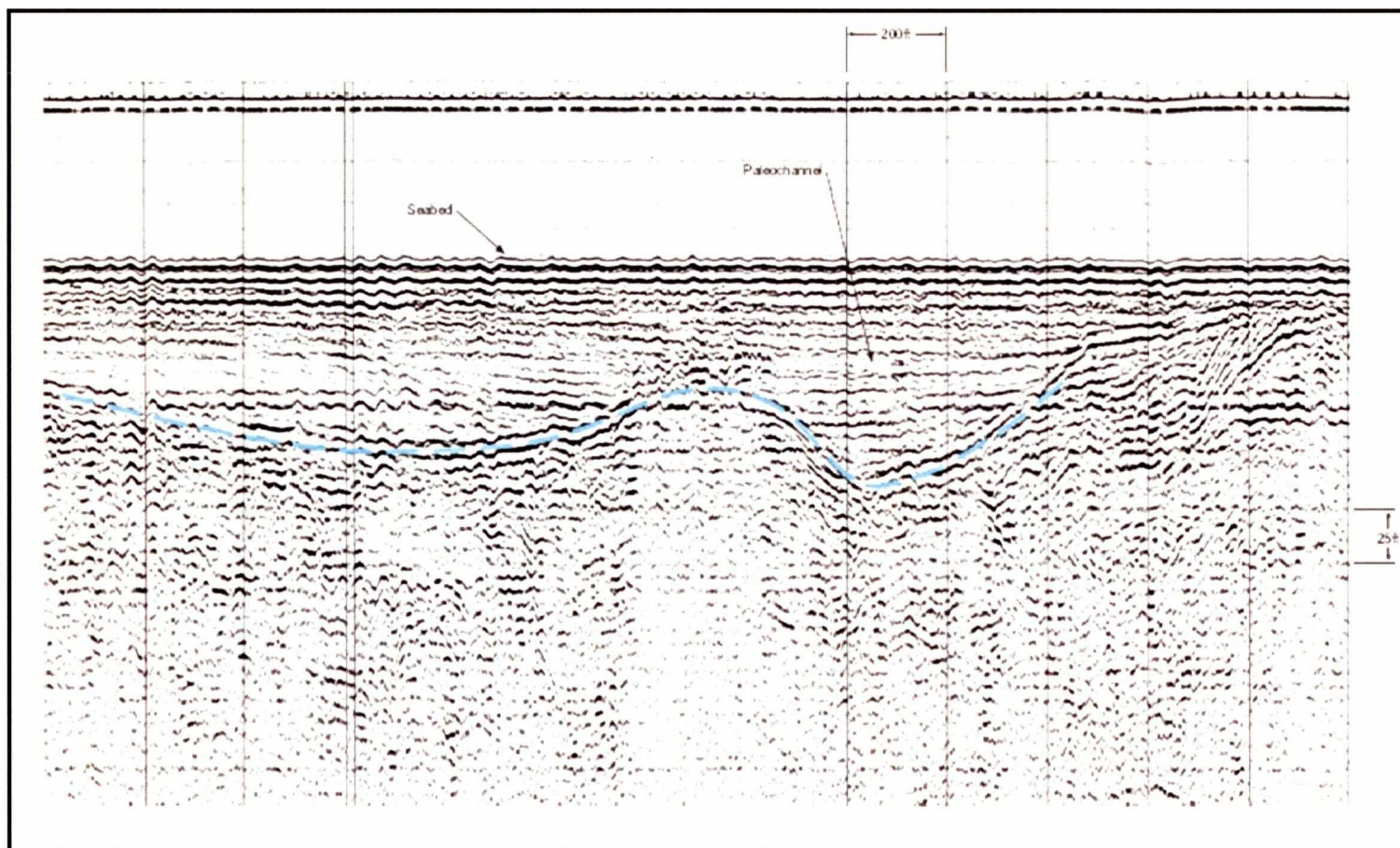


Figure 5.9: An example of the seismic reflection data showing the paleochannel obtained on "Platinum Cruise 05."

ones identified by USGS (Zelenka, 1988), is shown in **Figure 5.10**. It is observed that out of the three channels identified by Zelenka, (1988) the channel in the north closely coincides with the findings of the “Platinum Cruise 05.” Interpretation of **Figure 5.10** indicates that the channel identified from the seismic reflection data towards the south seems to be a continuation of the channel identified by Zelenka (1988). The location and position of this channel identified in the south indicates that it is probably the extension of the Salmon River, which is believed to have flowed into the present Chagvan Bay area in preglacial times, as documented by Mertie (1940). A summary of the analysis of magnetic and seismic data supports the first research hypothesis that the offshore region of Goodnews Bay contains buried channels which are near drowned ultramafic rocks and channels which could be extensions of the Salmon River.

In addition, the geophysical data analysis was followed by the satellite image analysis for determining the sediment distribution pattern.

5.3 IMAGE ANALYSIS FOR THE SEDIMENT DISTRIBUTION PATTERN

The objective of the satellite image analysis was to obtain information on the sediment distribution pattern in the offshore region of Goodnews Bay. This information on the sediment distribution pattern is critical because it will help in characterizing areas of low and high energy current environments and also in understanding the transport processes in this region. The Landsat natural color composites are considered to be useful

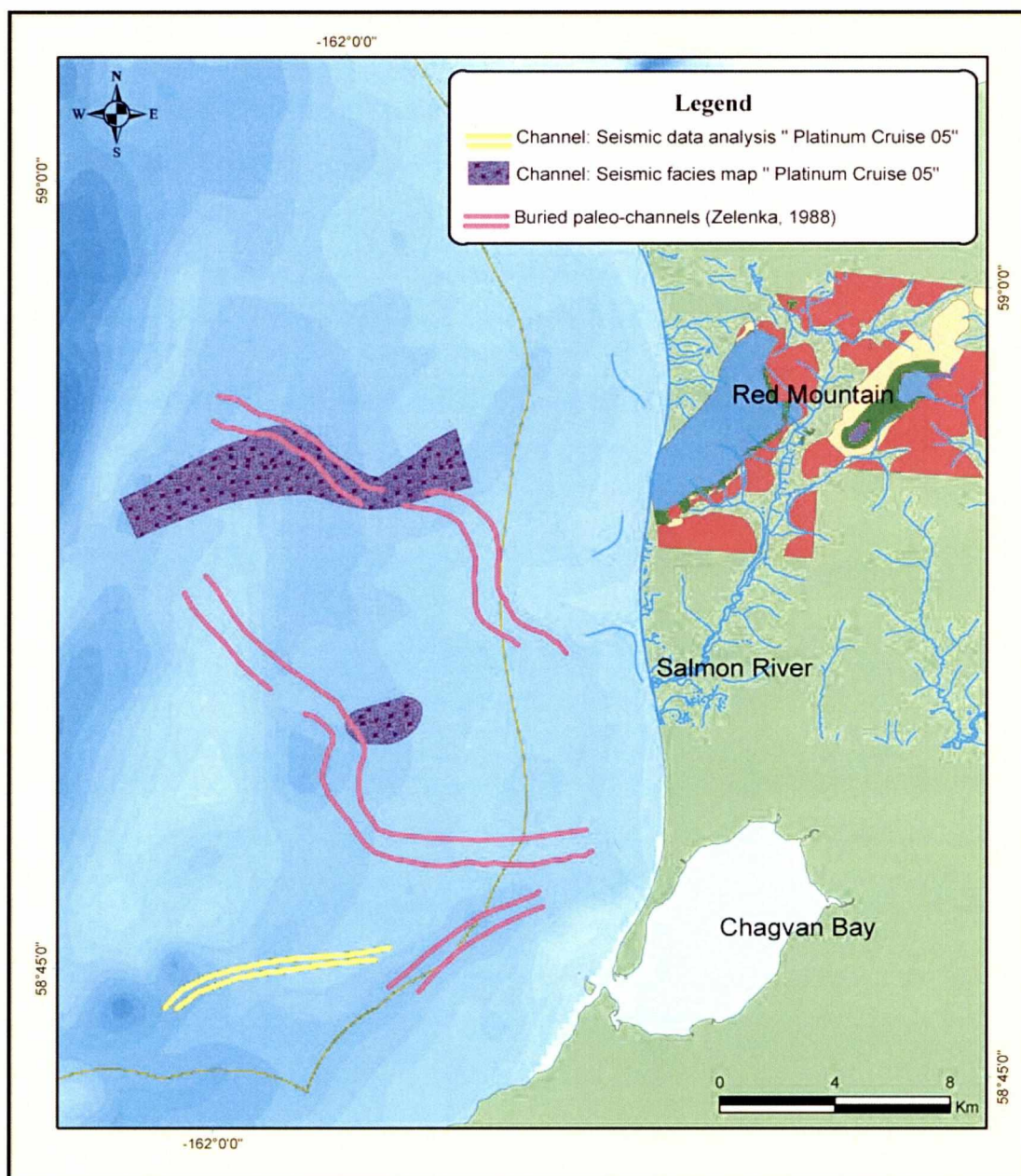


Figure 5.10: A comparative map showing the channels identified from the data obtained on "Platinum Cruise 05," and the channels identified by USGS and published by Zelenka (1988).

inputs for sediment load and bathymetry studies because its sensors detect visible light from a wider portion of the visible spectrum than other satellite sensors (Edwards and Mumby, 1999). Hence, the image used for this analysis was a natural color composition of Landsat 7 ETM acquired on 27th September 2000. In order to obtain a better visualization of the sediment distribution pattern in water, a contrast stretching image enhancement was applied. The intent of contrast stretching was to broaden the narrow range of reflectance values typically present in an input image over a wider range of grey values (Lillesand et al., 2004). **Figures 5.11 a and b** show the original and the enhanced image of the study area. The enhanced image showed that there is a large sediment load inside Goodnews Bay and the area close to Carter Bay in the north. The large amount of sediment load characterizes these areas as low energy environments. The enhanced image was further overlaid with the map showing the direction of longshore sediment transport due to coastal currents developed by USGS (Hunter et al., 1979). **Figure 5.12** shows the combined figure of enhanced image and longshore sediment transport direction.

Figure 5.12 shows that the longshore sediment transport direction could be the reason for the large sediment load inside the Goodnews Bay and areas close to Carter Bay. The reason for this large sediment load could be the movement of the coastal currents into the bay and the eddy current formation in the Carter Bay. It is observed from the enhanced image that the sediment load is greatest in these two places (brighter reflectance observed due to the sediment load in water). In the next chapter this enhanced image of sediment load will be compared to the distribution of platinum to study the

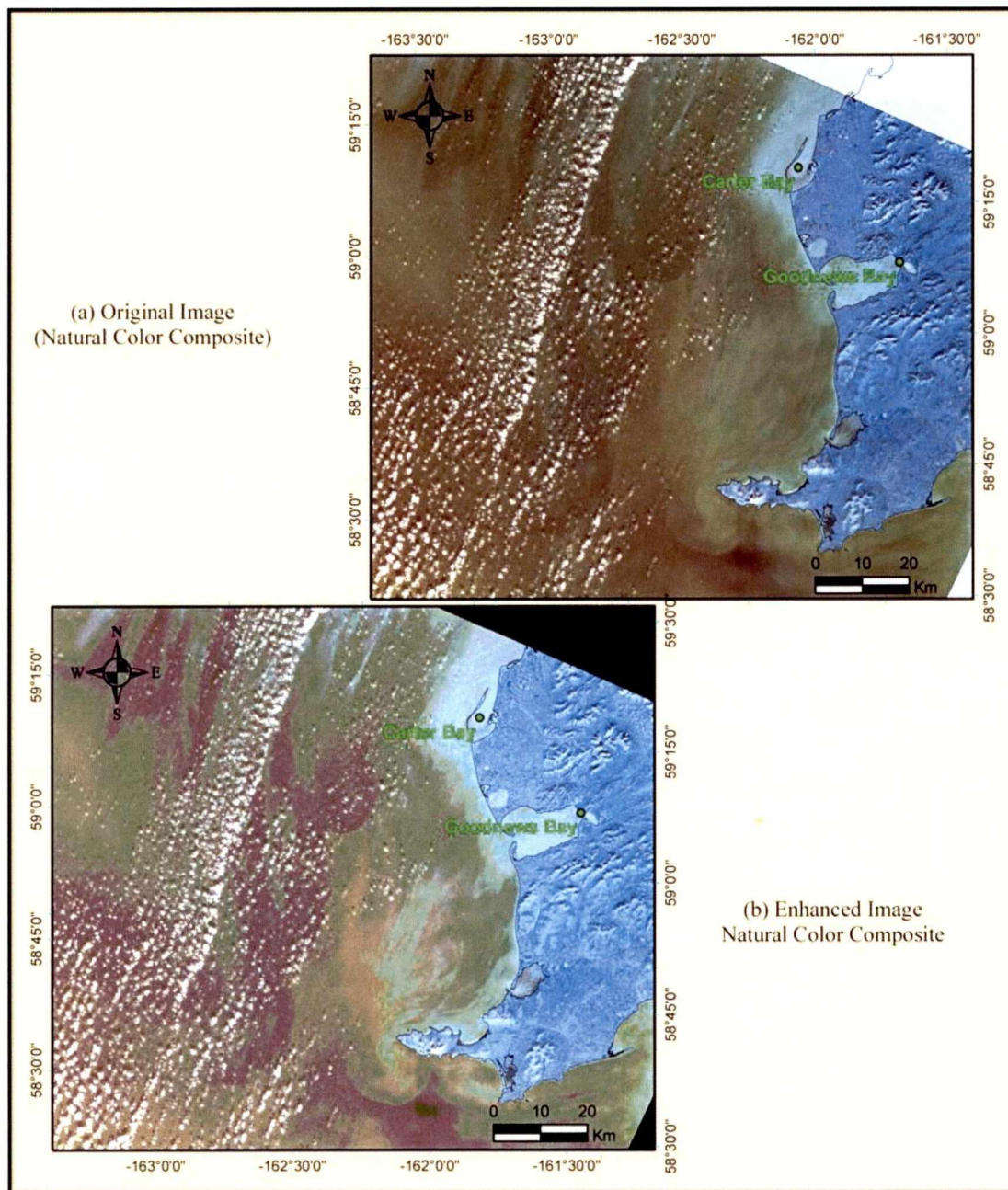


Figure 5.11: (a) Image showing the natural color composite of the Landsat 7 ETM (b) Enhanced image using contrast stretch, showing the sediment load pattern in the offshore region of Goodnews Bay.

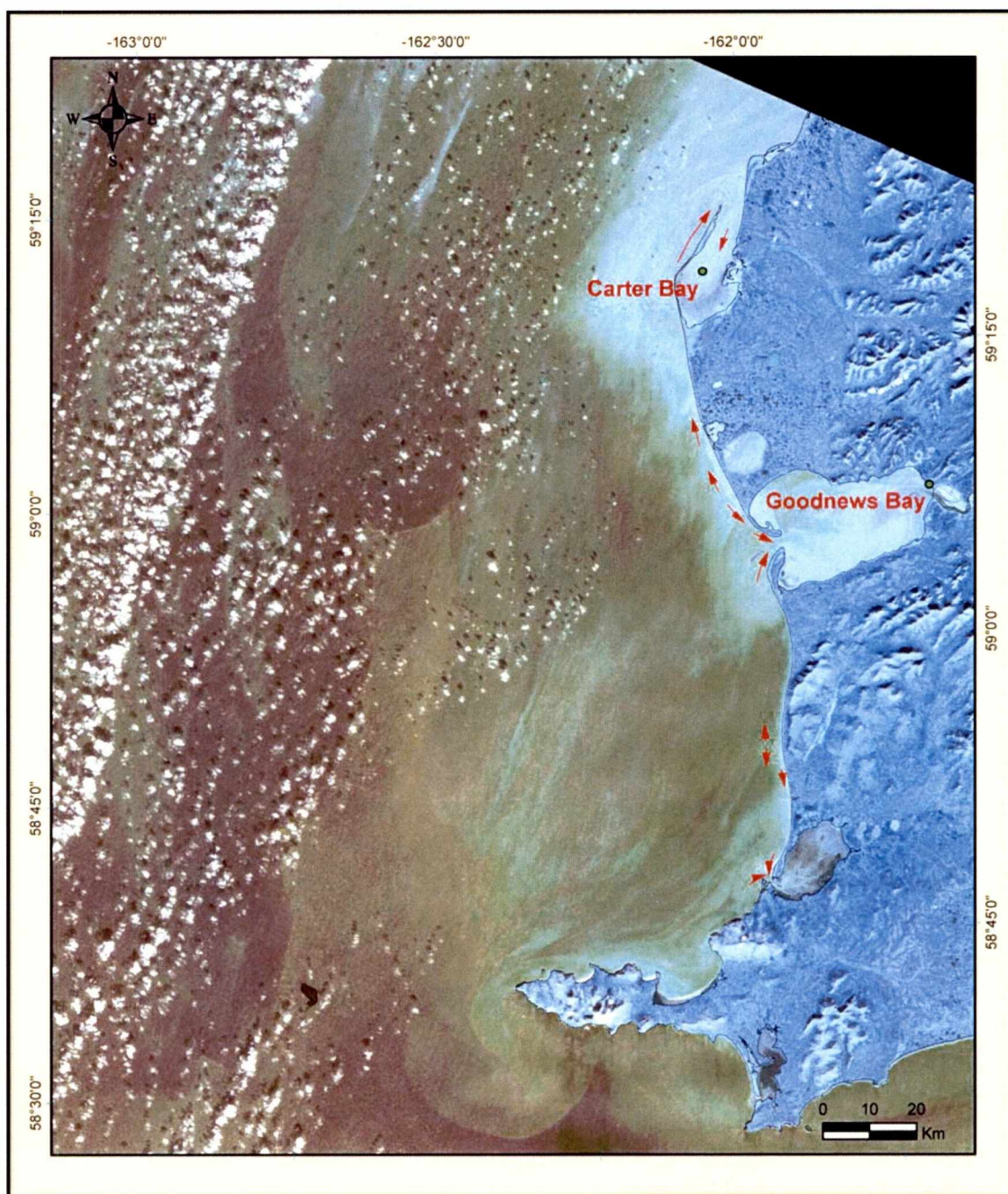


Figure 5.12: Comparison of the longshore sediment transport direction developed by the USGS (Hunter et al., 1979) with the sediment load distribution obtained from enhanced image.

influence of coastal currents on the transport processes of heavy minerals in the offshore region of Goodnews Bay. The next step was to analyze the various properties of the platinum data available in the geodatabase.

5.4 EXPLORATORY DATA ANALYSIS

There are a total of 477 point locations having platinum values from the offshore region of Goodnews Bay. These 477 data points have been sampled and analyzed for platinum by 5 different agencies over the last 5 decades. The number of samples collected by each agency and the sample locations are shown in **Figure 5.13**. Out of the 477 data points, 77 were samples collected within Goodnews Bay and 400 collected outside the bay. It was also found that 131 points are in federal water limits and the remaining 346 points are in state waters.

A statistical analysis was done to derive inferences on the platinum distribution of the study area. The two major analysis techniques used were the histogram analysis and the global trend analysis. The histogram analysis was carried out to understand the statistical distribution of the data. The histogram plot of the platinum data is shown in **Figure 5.14**. The histogram illustrated a highly skewed distribution of the platinum resources in the study area. The majority of the data comprised extremely low concentrations of platinum. The statistics of the platinum data are provided in **Table 5.2**, and it showed that the data have a skewness of 1.85 and a mean and standard deviation of 190.79 and 235.93, respectively.

The global trend analysis tool available in ArcGIS 9.1 was used to determine the

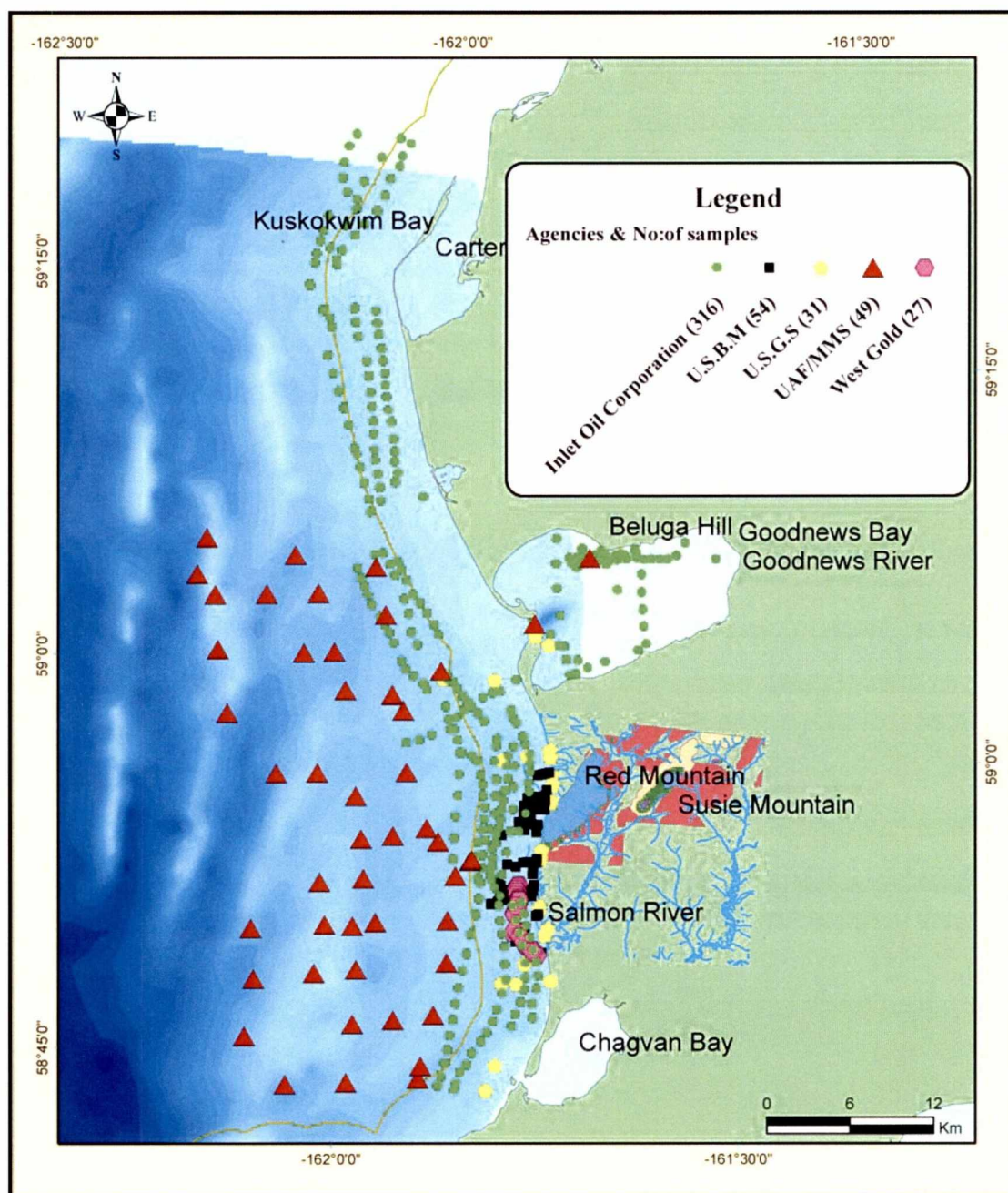


Figure 5.13: Sample locations of platinum data collected by various agencies in the offshore region of Goodnews Bay.

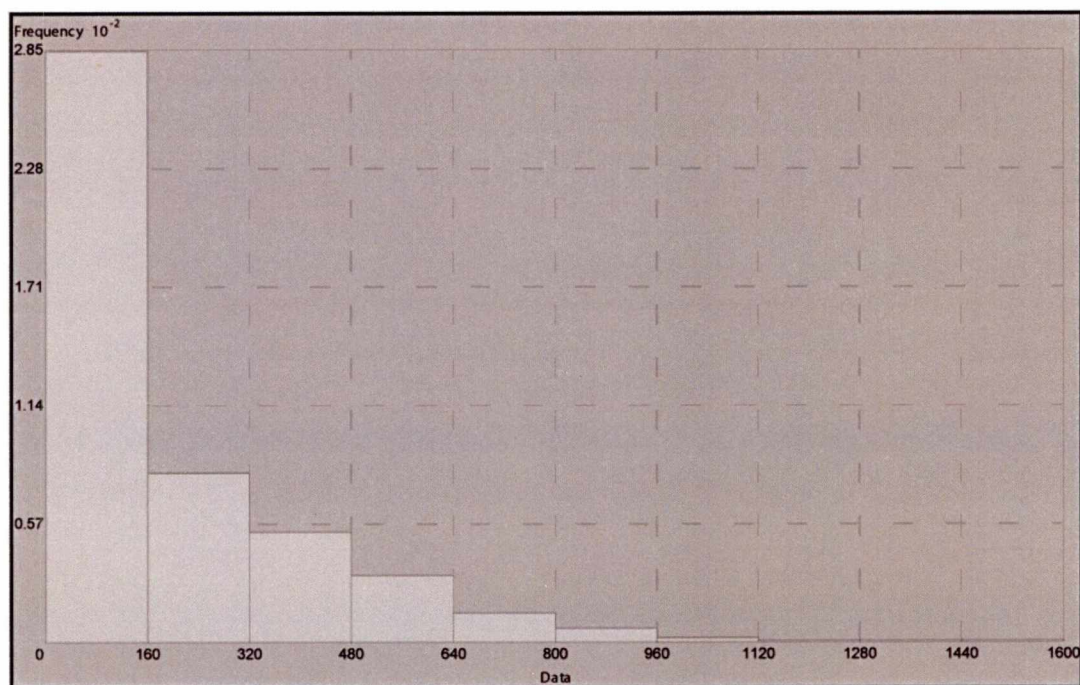


Figure 5.14: Histogram plot of platinum data for the 477 sample locations shown in Figure 5.13.

Table 5.2: Summary statistics of platinum data.

Count: 477	Standard Deviation: 235.93
Minimum: 0mg/m ³	Skewness: 1.85
Maximum: 1600mg/m ³	Kurtosis: 7.59
Mean: 190.79	Median: 100

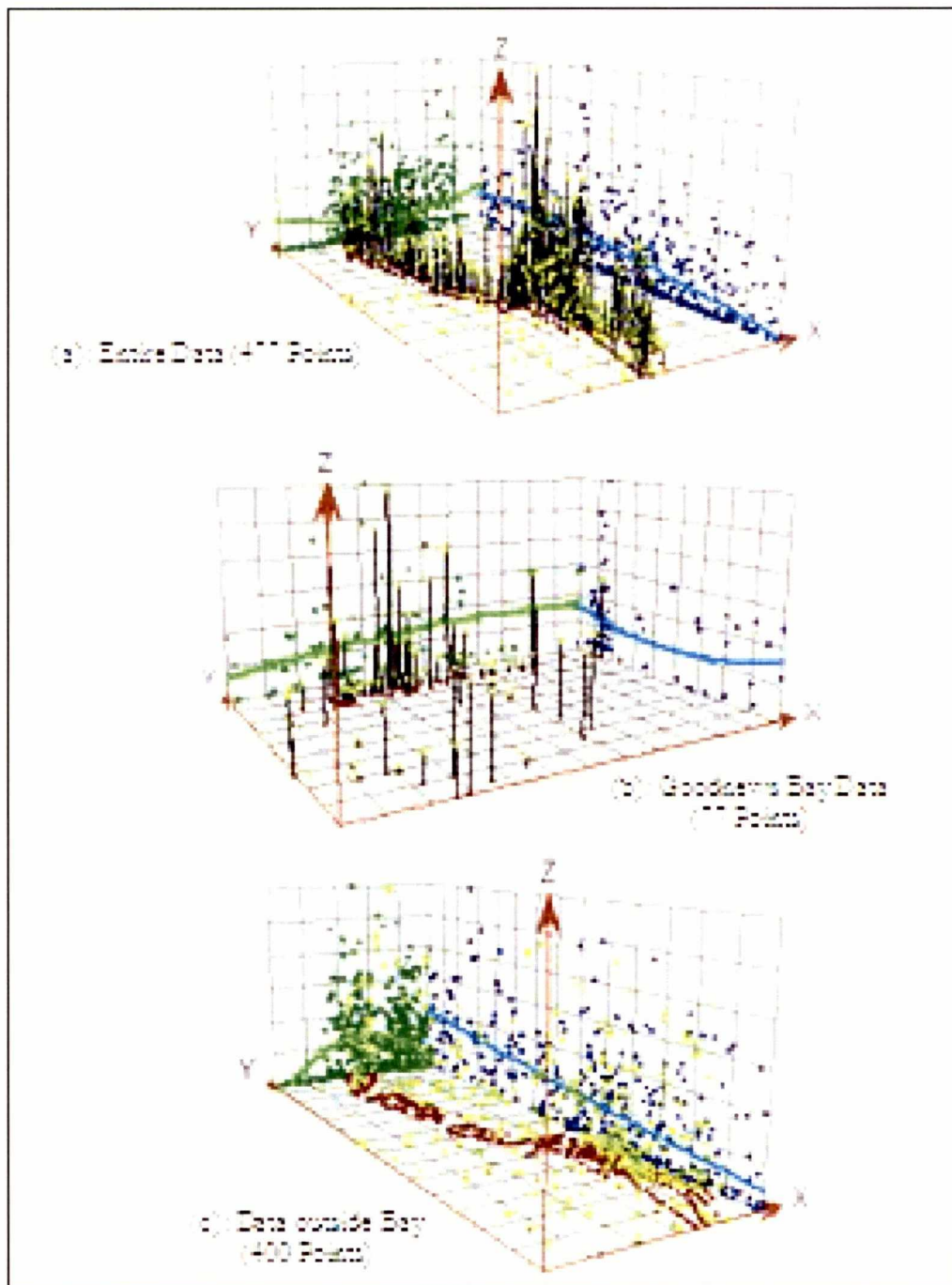
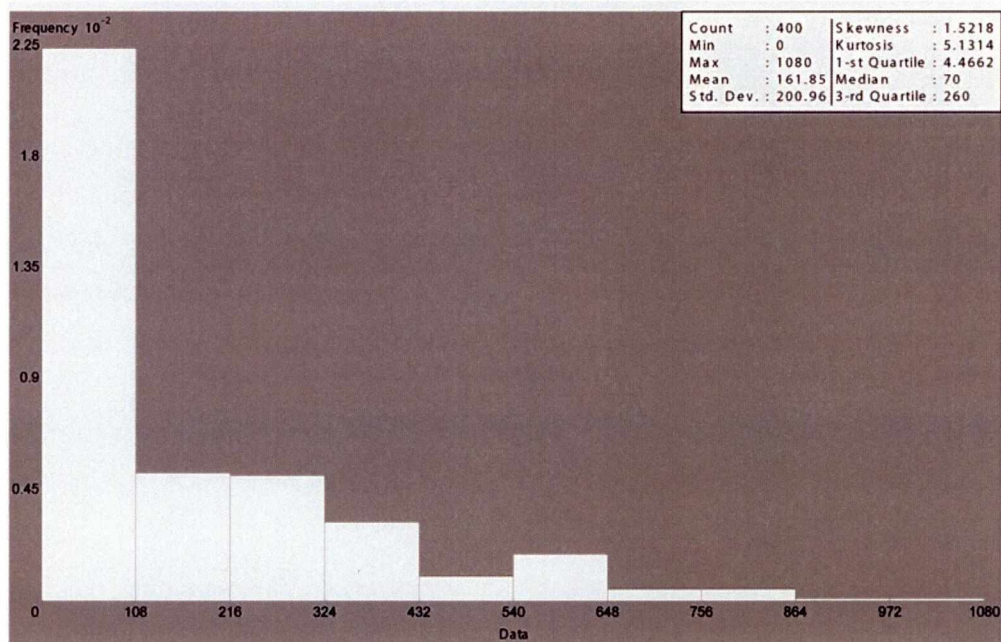


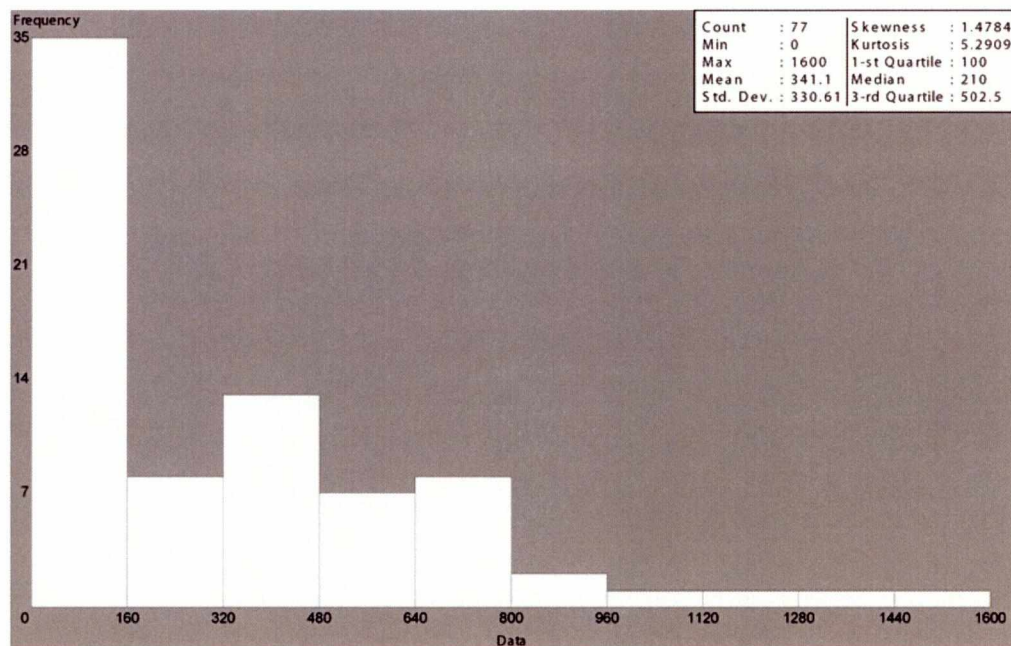
Figure 5.15: Surficial trends in platinum distribution, x-y represents south-north direction and y-x represents west-east direction (a): Trend of entire platinum data (b): Trend of data inside the bay (c): Trend of data outside the bay.

presence/absence of spatial trends in the platinum data. The trend analysis plot is shown in **Figure 5.15**. In the trend analysis plot, the vertical lines represent the platinum value at each sample location. The platinum values were further projected onto the perpendicular planes (east-west and north-south). A best fit line fitted through the projected points describes the trend in a specific direction. **Figure 5.15 (a)** shows that when the entire dataset is considered it depicts a northward trend (x-y direction), i.e., the platinum values are increasing from south to north. It is also observed that the trend in the east-west (y-x) direction is negligible. The data were further split to analyze the trend within the Goodnews Bay data and the data from outside the bay. **Figure 5.15 (b)** shows that the data from inside Goodnews Bay are almost free from trends in both north-south and east-west directions. The trend analysis of the data from outside the bay is shown in **Figure 5.15 (c)**. It is observed from **Figure 5.15 (c)** that the data outside the bay depict strong trends in both the north-south and east-west directions. In the north-south direction it is found that the values of platinum increase towards the north, whereas in the east-west direction values of platinum increase in the center and decrease towards both east and west. Since the data from inside the Goodnews Bay are free from spatial trends and data from outside the bay have a trend, for the platinum distribution analysis, the data were split and analyzed separately for inside and outside the bay.

The histogram plot of the split data was analyzed to verify the distribution. **Figure 5.16 (a)** and **Figure 5.16 (b)** show the histogram plots for the data from outside the bay and inside the bay, respectively. The histograms revealed that the data are still positively



(a)



(b)

Figure 5.16: Plot showing (a): histogram for the platinum data from outside the bay (b): histogram for the platinum data from inside the bay.

skewed in both the cases. However, the skewness has reduced from 1.85 (in case of entire data) to 1.52 and 1.47 for outside and inside the bay, respectively.

It was also noted that the data points inside the bay were sampled and analyzed by a single agency using the same analytical procedure, whereas the data points outside the bay were analyzed by 5 different agencies using two different analytical procedures. The difference in the analytical procedure was that two of the agencies analyzed the entire sample for platinum, while the other three analyzed the heavy mineral crop obtained from the entire sample. The three organizations that analyzed the heavy mineral crop for platinum converted the final platinum value to represent the whole sample. However, this led to the analysis of the data from each agency separately to identify whether there is any difference in the statistical properties of these data.

5.4.1 Statistical Analysis

A simple analysis of the mean platinum value obtained by each of these agencies is given in **Table 5.3**. **Table 5.3** shows that the mean platinum value obtained by the analysis of entire sample for platinum, without heavy mineral separation, is several times higher than that for the samples analyzed for platinum with heavy mineral separation. This raised the question of whether there was loss of platinum in the heavy mineral separation process. **Figure 5.17** shows the graph provided by ODM (refer to Section 4.4.2 for details) for heavy mineral separation for gold recovery. Assuming these data could be applied to platinum loss (since the specific gravity of platinum is close to that of

Table 5.3: The minimum, maximum and mean value of platinum obtained by different agencies in the offshore region of Goodnews Bay.

	Minimum Pt (Mg/cu.m)	Maximum Pt (Mg/cu.m)	Mean Pt (Mg/cu.m)	Sample Fraction Analyzed
Inlet Oil Corp	20	1600	270	Whole Sample
USGS	10	700	120	Whole Sample
USBM	0	180	7	Heavy Mineral
WestGold	0	40	2	Heavy Mineral
UAF	0	70	5	Heavy Mineral

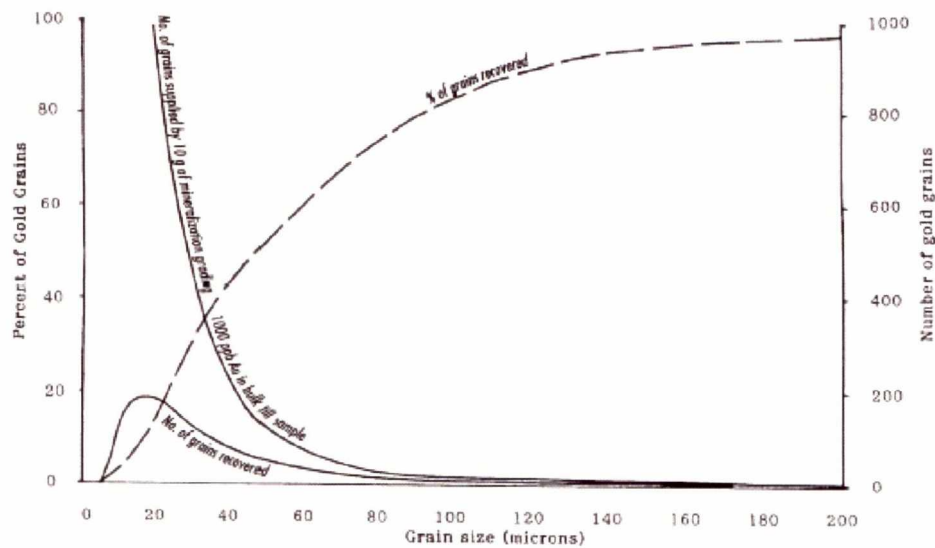


Figure 5.17: Plot of gold recovery vs. grain size during heavy mineral separation. Obtained from ODM Laboratories, Ontario, Canada (agency who carried out heavy mineral separation for platinum samples obtained from “Platinum Cruise 05”).

gold), it is observed from **Figure 5.17** that there is a considerable loss in the recovery of gold/platinum when the particle size is less than 100 microns. The grain size distribution analysis of platinum carried out by Moore (1971) suggests that the silt-clay fractions (0-100microns) were the richest in platinum in the offshore region of Goodnews Bay. Representative values of platinum in different size fractions by Moore (1971) were 73.80% of the platinum in the silt-clay fraction (0-100 micron) and 26.20% > 100 micron. Comparing this grain size distribution of platinum to **Figure 5.17** suggests a big loss of platinum in the heavy mineral analysis. Taking into account this loss factor involved in the heavy mineral separation the distribution of platinum data points outside the bay was modeled two times separately. Modeling without the incorporation of the loss factor is referred to as modeling outside bay-1 and the hypothetical data with inclusion of loss factor is termed modeling outside bay-2. The heavy mineral separation was not used in the analytical process of the platinum data points inside the bay; hence, no loss factor was applied to these data.

5.4.2 Loss Factor Incorporation

Considering the grain size distribution of platinum presented by Moore (1971) to be representative of the offshore region of Goodnews Bay, it was inferred that the size fractions were 73.80% (0-100micron) and 26.20% (>100 micron). Therefore, the platinum values reported from the offshore region of Goodnews Bay should be 73.80% from the (0-100micron) grain size and 26.20% from the (>100 micron) grain size.

Figure 5.17 indicates that the loss of grains recovered in the size fraction > 100 micron is negligible, whereas the loss is about 50% in the 0-100 micron size range (assuming the average grain size in 0-100 micron to be 50 microns). Therefore, if the reported platinum value is x Mg/Cu.m.

It can be expressed as:

$$x = 0.7380x + 0.2620x$$

Where

$0.7380x$ = platinum in the 0-100 micron grain size range

$0.2620x$ = platinum in the >100 micron grain size range

Since the loss in 0-100 micron grain size fraction is 50% the equation incorporating the loss factor is given as:

$$x' = 2(0.7380x) + 0.2620x$$

Where

x' = Platinum value corrected for the loss in 0-100 micron grain size range.

The loss factor was applied to all those samples that were analyzed for platinum using heavy mineral separation.

After the platinum data were explored and corrected for the loss factor, the next step was to use these data to model the distribution of platinum in the study area.

6.0 ANALYSIS AND SYNTHESIS OF THE PLATINUM DISTRIBUTION

6.1 INTRODUCTION

There are four objectives in the analysis of the platinum distribution. Firstly, the exploratory data analysis in the last chapter (Section 5.4) suggested that the distribution of platinum has a different spatial trend inside and outside the bay. In order to analyze the platinum distribution in the study area, the analysis was accordingly split into two components. Secondly, the exploratory data analysis also revealed that there was a loss of platinum for the samples from stations outside the bay due to the different approaches taken for the geochemical analysis. The data outside the bay were analyzed once again with the incorporation of this loss factor. Thirdly, the distribution of platinum modeled outside and inside the bay was further combined to present the distribution of platinum for the entire study area. Finally, the combined distribution of platinum was compared to the results of the geophysical explorations, sand bars, coastal current direction and the satellite imagery analysis to determine the factors influencing the distribution of platinum in the study area.

These factors help to test the hypothesis on the influence of sand bars in the concentration of platinum, and also to assess the influence of the various depositional environments (placer and chemically weathered).

6.2 METHODS OF ANALYSIS AND PERFORMANCE MEASURES

The distribution of platinum was analyzed using both classical geostatistical techniques and a machine learning algorithm. The classical geostatistical techniques used included inverse distance weighting (IDW), global polynomial interpolation (GPI), local polynomial interpolation (LPI), kriging and cokriging. These analyses were done using ArcGIS 9.1 geostatistical analyst. The machine learning algorithm used was the support vector regression (SVR). The e1071 and kernlab package in the R-programming language were used for the machine learning algorithms (Meyer, 2006; Karatzoglou et al, 2004).

A major limitation of any analysis (model) is to verify its reliability. Perhaps the most rigorous way to analyze the reliability of a model is to collect additional data and compare those to the model predictions. This process is expensive and, at times, would be subject to limitations such as inaccessibility of the study area, the time required to collect samples, or unavailability of equipment, skilled labor, and so on. The alternatives available in this context are to use the same data for both training/developing the model and testing, or a subset of the data for training and the other subset for testing.

However, when the model is being developed and tested on the same data the machine learning algorithms suffer from the curse of over-fitting, which may allow accurate modeling of the training data, but when verified on a independent testing set the performance of the model may be extremely poor (Foody and Mathur, 2004). Therefore, the most reliable method to verify the model when it is not possible to collect additional

data for validation is to use a subset of the actual data for testing that was not used for developing/training the model (Dutta, 2006a).

In this regard, prior to the model development, the available data were split into two random subsets of 80% and 20%. One subset of the data was used for developing the model (training data, 80%) and the other subset was used to verify the reliability (testing data, 20%). The reason for using 80% of the data for training was to provide a good number of data points for the model development. This same concept of training and testing data was used to verify the reliability of the various geostatistical techniques and the machine learning algorithm used in this study. The model parameters for the different techniques were determined by K-fold cross validation of the training data. The parameters that gave the minimum RMSE were considered the best parameters for that particular technique.

Once the method for determining the reliability of the model was established, the next question was which measures would be used to judge the reliability. In this study, the error in the predicted versus the observed (testing data) was calculated using several performance measures such as Root Mean Square Error (RMSE):

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (P_i - O_i)^2}{N}} \quad (6.1)$$

Mean Absolute Error (MAE):

$$MAE = \left(\sum_{i=1}^N |P_i - O_i| \right) / N \quad (6.2)$$

Correlation Coefficient (r):

$$r = \frac{\sum_{i=1}^N \{(O_i - \bar{O})(P_i - \bar{P})\}}{\left\{ \sum_{i=1}^N (O_i - \bar{O})^2 \sum_{i=1}^N (P_i - \bar{P})^2 \right\}^{0.5}} \quad (6.3)$$

Coefficient of Determination (R^2):

$$R^2 = \left\{ \frac{\sum_{i=1}^N (O_i - \bar{O})(P_i - \bar{P})}{\left[\sum_{i=1}^N (O_i - \bar{O})^2 \right]^{0.5} \left[\sum_{i=1}^N (P_i - \bar{P})^2 \right]^{0.5}} \right\}^2 \quad (6.4)$$

and Coefficient of Efficiency (E):

$$E = \left\{ 1 - \frac{\sum_{i=1}^N (O_i - P_i)^2}{\sum_{i=1}^N (O_i - \bar{O})^2} \right\} \times 100 \quad (6.5)$$

where

O_i = Observed value, P_i = Predicted value, \bar{O} = Mean of the observed value,

\bar{P} = Mean of the predicted value and N = Number of observations.

Out of all the various performance measures, the most widely used evaluation for the validation of models that has been used in the past is the correlation based measure i.e. the r and R^2 . However, they have several limitations such as insensitivity towards additive and proportional difference occurring between the observed and the predicted data, and the oversensitivity to outliers leading to a bias towards extreme events.

According to Legates and McCabe (1999, pp.234) “This can be easily demonstrated by

the example of $P_i = AO_i + B$ for any nonzero value of A and any value of B , the $R^2 = 1$.”

These limitations of the correlation based measures are well documented (Willmott, 1981; Willmott et al, 1985; Kessler and Neas, 1994; Legates and Davis, 1997; Legates and McCabe, 1999). The coefficient of efficiency was an improvement over the correlation based measures, because it is sensitive to the observed and predicted means and variances, but it is also limited by the oversensitivity to outliers (Nash and Sutcliffe 1970; Legates and McCabe, 1999).

When RMSE is equal to MAE, then it means that all the errors have the same magnitude. The difference between the RMSE and the MAE is an indicator of the extent to which outliers exist in the data (Legates and McCabe, 1999). The MAE describes the average magnitude difference between the actual and the predicted. When MAE is zero then the predicted is equal to the actual.

Utilizing the capability of the RMSE, MAE and coefficient of efficiency, a new index term known as the performance index (PI) was developed, to compare the predictability of the different models, which is described by equation 6.6.

$$PI = (RMSE - MAE) + MAE + (100 - E) \quad (6.6)$$

The PI will vary from 0 (perfect model) to infinity (poor model). However, the performance index like the coefficient of efficiency is just a relative assessment of the model performance. Evaluating the statistical significance of correlation based measures is easy due to its well defined statistical distributions. In the case of PI no such statistical significance has been established, and is beyond the scope of this work. However,

statistical significance could be evaluated using bootstrap methods. A complete discussion of the bootstrap methods and their use to determine statistical significance are well documented (Efron, 1981a, b; Efron and Gong 1983).

6.3 ANALYSIS OF THE PLATINUM DISTRIBUTION INSIDE GOODNEWS BAY

As introduced in the beginning of this chapter, various models and performance measures were utilized to assess and validate the platinum distribution within Goodnews Bay. The bay has 77 data points of platinum concentrations, as shown in **Figure 6.1**. These points were randomly split into training and testing datasets. The training dataset was comprised of 61 data points (80%), and the testing dataset of 16 points (20%).

This section provides the results for the various geostatistical techniques. In the subsequent section (Section 6.3.2), a thorough comparative analysis and synthesis of these model predictions are provided.

6.3.1 Geostatistical Techniques

The basic principles and the equations used for the various geostatistical techniques applied to model the distribution of platinum in the study area are described extensively by Isaak and Srivastava (1989), Clark and Harper (2000), and Johnston (2003). A brief description and the results obtained using the different geostatistical methods are provided below.

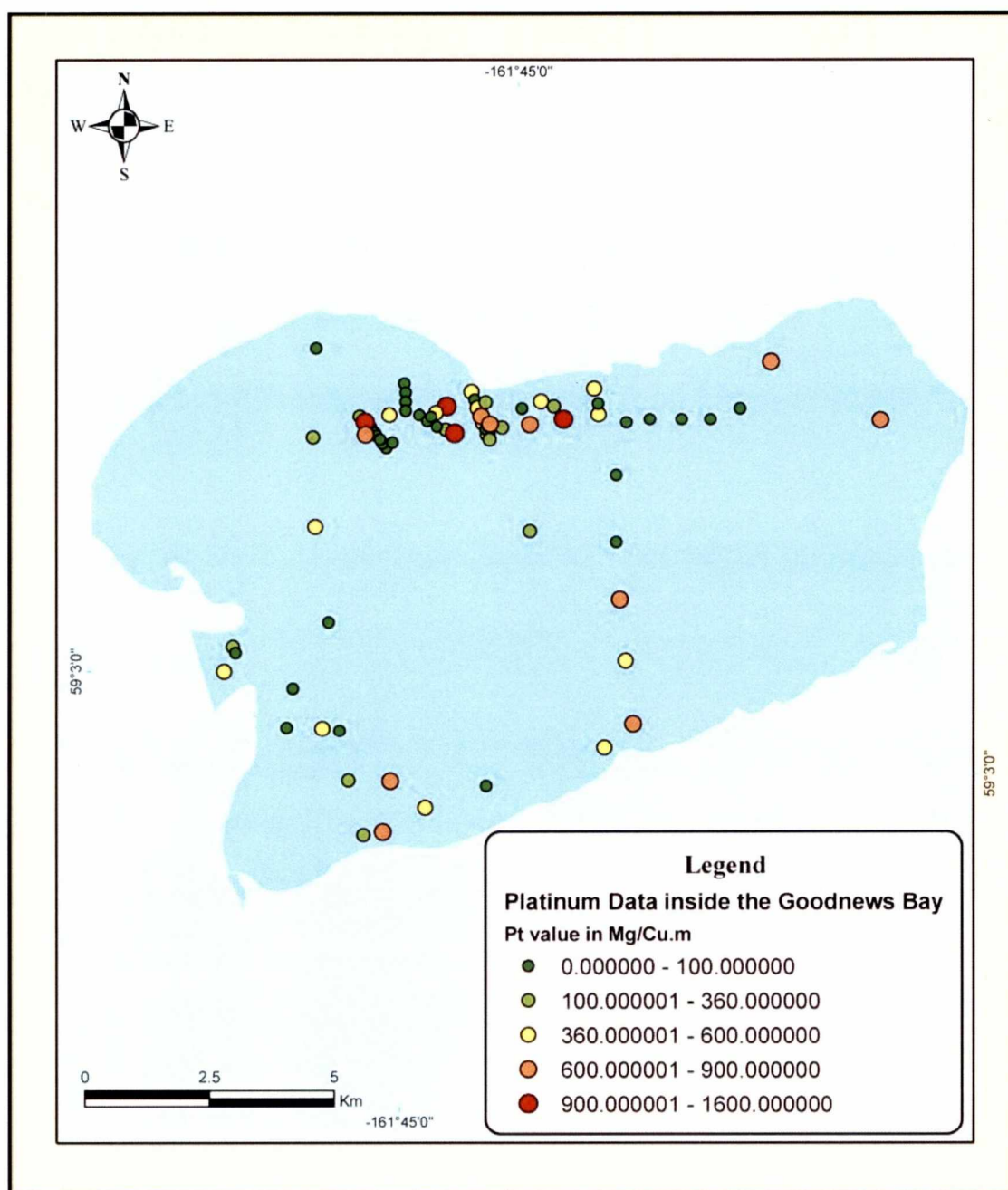


Figure 6.1: Map showing the available platinum data from the Goodnews Bay (77 points).

6.3.1.1 Inverse Distance Weighting

The basic assumption of the IDW is that each predicted point has a local influence that reduces with distance, or, in other words, the values closer to the predicted value would have more influence than the values farther apart. The weighting factor given in equation 6.7 determines the influence of a known point on any unknown point.

$$w(d) = \frac{1}{d^p} \quad (6.7)$$

Where

$w(d)$ = weighting factor,

d = the distance from the known value to the unknown value,

and p = is a user-selected power factor.

The rate at which the influence diminishes with distance is determined by p .

ArcGIS 9.1 geostatistical analyst, automatically optimizes p based on the minimum RMSE. The various parameters used for the IDW model of the platinum data inside the bay are given in **Figure 6.2**. **Table 6.1** shows the performance measures obtained for the validation of the IDW model using the testing data. **Figure 6.3** shows the scatter plot for the predicted against the actual platinum values. The scatter plot of the 20% testing data shows that the IDW model is able to predict the median values approximately, while the lower values are over-predicted and the higher values are grossly under-predicted.

Table 6.1: Performance measures for the IDW model obtained during the validation using the platinum data from inside the bay. The model was validated using a testing data (Random split: 80% training and 20% testing).

<i>Method</i>	<i>RMSE</i>	<i>MAE</i>	<i>r</i>	<i>R</i> ²	<i>E</i>
IDW	267.67	219.14	0.48	0.23	21.07

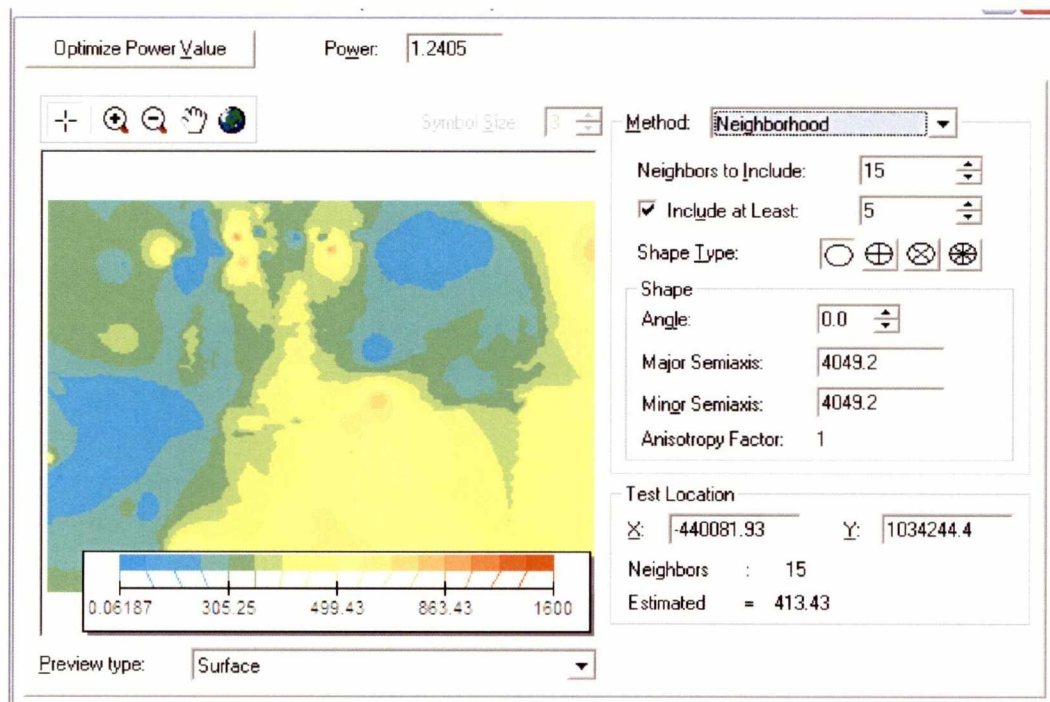


Figure 6.2: Parameters used for the IDW model for platinum data from inside the bay.

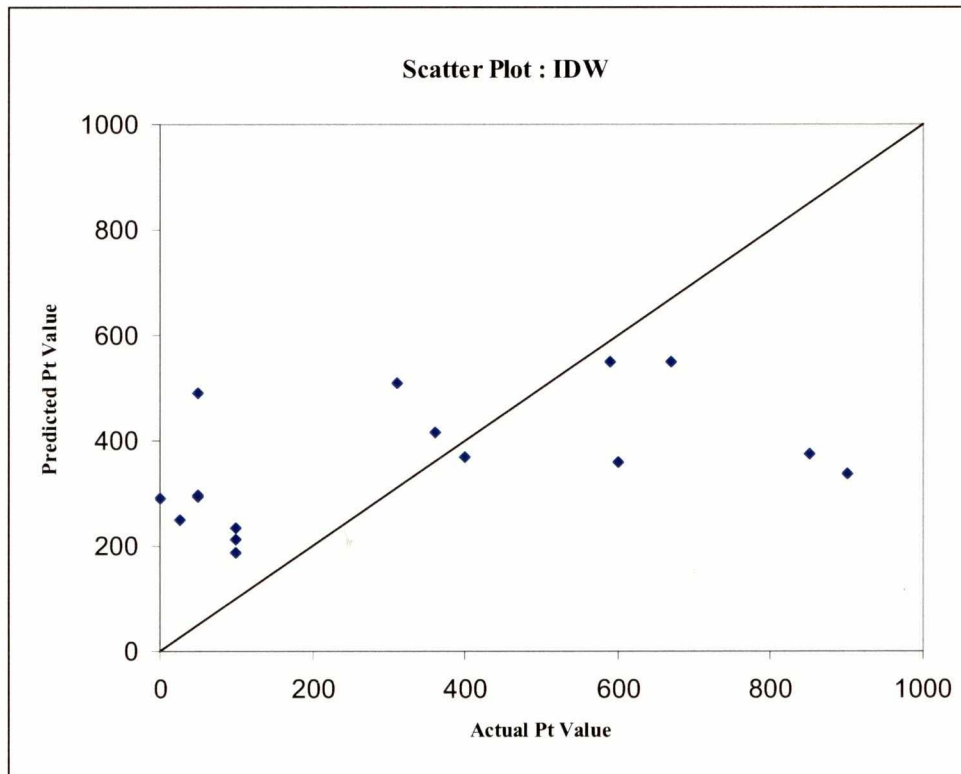


Figure 6.3: Scatter plot for the IDW model testing data for platinum. The x-axis represents the actual data, versus the predicted data on the y-axis.

6.3.1.2 Global Polynomial Interpolation

The GPI fits a smooth polynomial function to the training data. In this analysis, a polynomial function of the order three was used. **Table 6.2** shows the performance measures obtained for the validation of the GPI model using the testing data. **Figure 6.4** shows the scatter plot for the predicted against the actual platinum values. It was found that the scatter plot of the GPI model, unlike that of the IDW model, does not show any strong correlation. The model under-predicts and over-predicts the low and high values, respectively. However, it is able to predict the median values with better accuracy.

Table 6.2: Performance measures for the GPI model obtained during the validation using the platinum data from inside the bay. The model was validated using a testing data (Random split: 80% training and 20% testing).

<i>Method</i>	<i>RMSE</i>	<i>MAE</i>	<i>r</i>	<i>R²</i>	<i>E</i>
GPI	464.68	358.29	0.36	0.13	-137.86

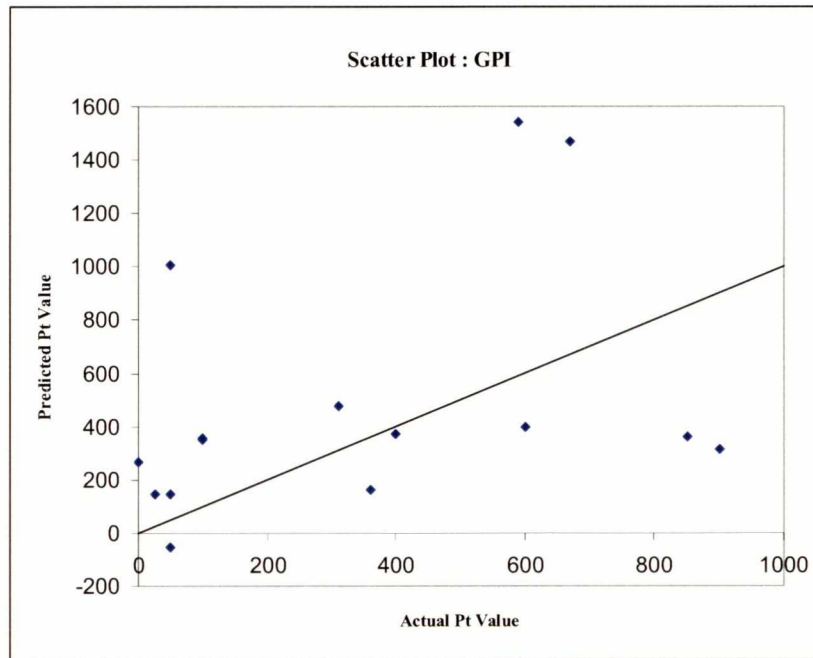


Figure 6.4: Scatter plot for the GPI model testing data for platinum. The x-axis represents the actual data, versus the predicted data on the y-axis.

6.3.1.3 Local Polynomial Interpolation

The difference between the GPI and LPI is that the GPI fits a polynomial function to the entire dataset, whereas the LPI fits several polynomials, each having a specified overlap. A polynomial function of the order three was used for the LPI modeling. **Table 6.3** shows the performance indicators obtained for the validation of the LPI model using the testing data. **Figure 6.5** shows the scatter plot for the predicted against the actual platinum values. It was observed from the scatter plot that the predictions using the LPI model exhibit a very similar prediction behavior to that observed for the GPI model.

Table 6.3: Performance measures for the LPI model obtained during the validation using the platinum data from inside the bay. The model was validated using a testing data (Random split: 80% training and 20% testing).

<i>Method</i>	<i>RMSE</i>	<i>MAE</i>	<i>r</i>	<i>R²</i>	<i>E</i>
<i>LPI</i>	<i>448.49</i>	<i>351.35</i>	<i>0.37</i>	<i>0.14</i>	<i>-121.58</i>

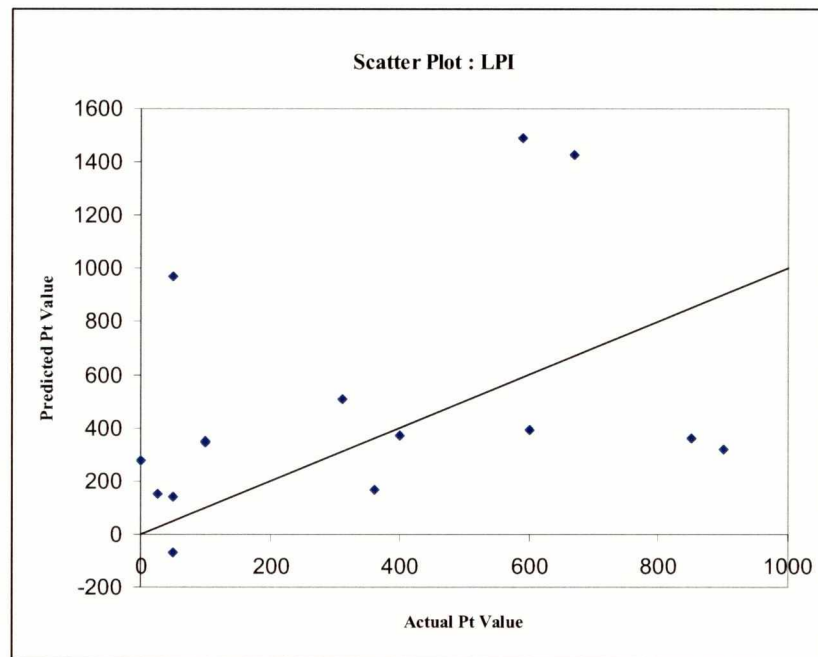


Figure 6.5: Scatter plot for the LPI model testing data for platinum. The x-axis represents the actual data versus the predicted data on the y-axis.

6.3.1.4 Radial Basis Function

The RBF is an exact interpolator where the surface passes precisely through all the training data. In ArcGIS 9.1 geostatistical analyst, there are five different basis functions; they are thin-plate spline, spline with tension, completely regularized spline, multiquadratic function, and inverse multiquadratic spline. Each of these basis functions develops a different interpolation surface. The various parameters used for the RBF model of the platinum data from inside the bay are given in **Figure 6.6**. **Table 6.4** shows the performance measures obtained for the validation of the RBF model using the testing data. **Figure 6.7** depicts the scatter plot for the predicted against the actual platinum values. It was observed from the scatter plot that the RBF model is able to predict the median values well, whereas it over-predicts low values and under-predicts high values similar to the IDW model.

Table 6.4: Performance measures for the RBF model obtained during the validation using the platinum data from inside the bay. The model was validated using a testing data (random split: 80% training and 20% testing).

<i>Method</i>	<i>RMSE</i>	<i>MAE</i>	<i>r</i>	<i>R²</i>	<i>E</i>
<i>RBF</i>	<i>255.09</i>	<i>200.64</i>	<i>0.57</i>	<i>0.33</i>	<i>28.31</i>

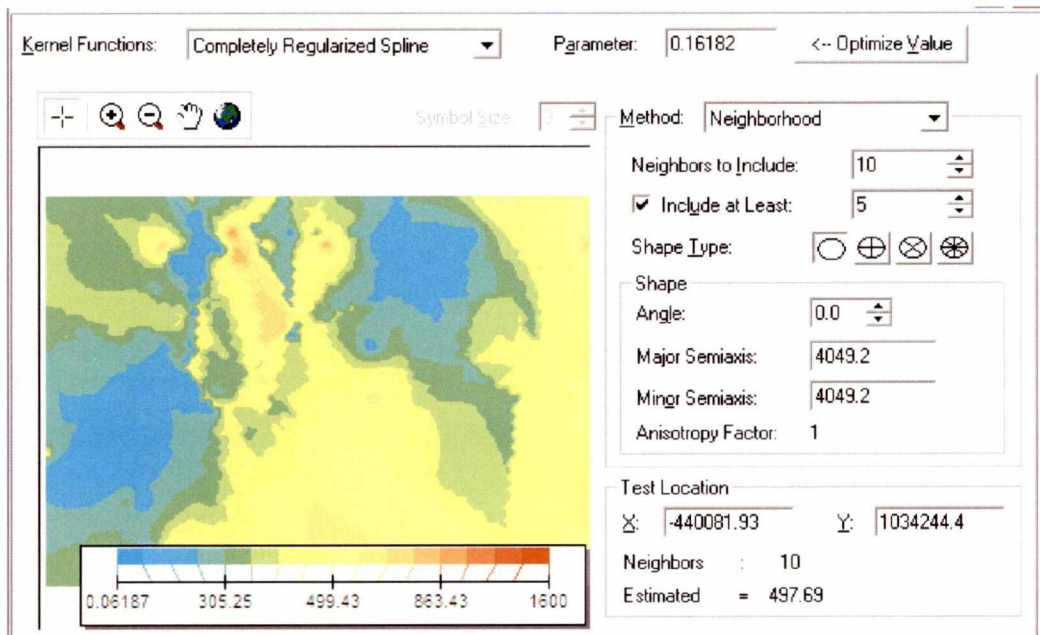


Figure 6.6: Parameters used for the RBF model for platinum data from inside the bay.

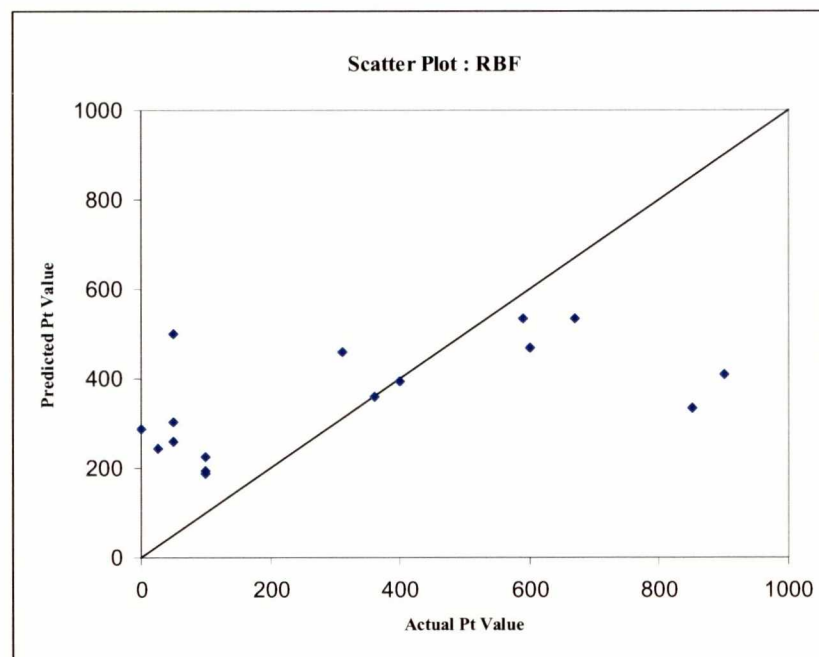


Figure 6.7: Scatter plot for the RBF model testing data for platinum. The x-axis represents the actual data, versus the predicted data on the y-axis.

6.3.1.5 Ordinary Kriging (OK)

In OK, the model used to predict the value is defined by

$$Z(s) = \mu + \varepsilon(s) \quad (6.8)$$

Where μ is the unknown mean and $\varepsilon(s)$ represents the variation around the mean.

OK is suitable for prediction of data having an unidentified trend. The various parameters used for the OK model of the platinum data inside the bay are given in **Figure 6.8**. **Table 6.5** shows the performance measures obtained for the validation of the OK model using the testing data. **Figure 6.9** shows the scatter plot for the predicted against the actual platinum values. The scatter plot illustrates that the OK model is over-predicting the low values and under-predicting median and high values.

Table 6.5: Performance measures for the OK model obtained during the validation using the platinum data from inside the bay. The model was validated using testing data (random split: 80% training and 20% testing).

<i>Method</i>	<i>RMSE</i>	<i>MAE</i>	<i>r</i>	<i>R²</i>	<i>E</i>
OK	337.03	295.72	-0.18	0.04	-25.13

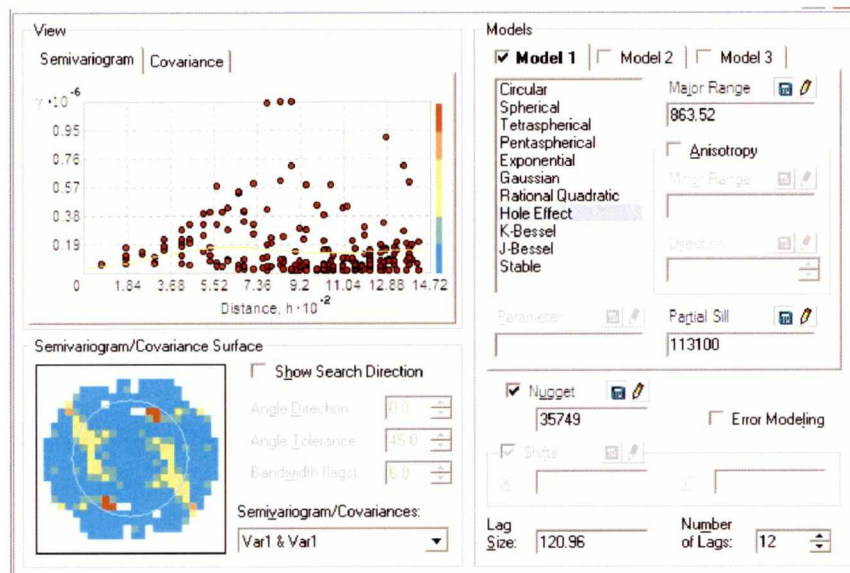


Figure 6.8: Parameters used for the OK model for platinum data from inside the bay.

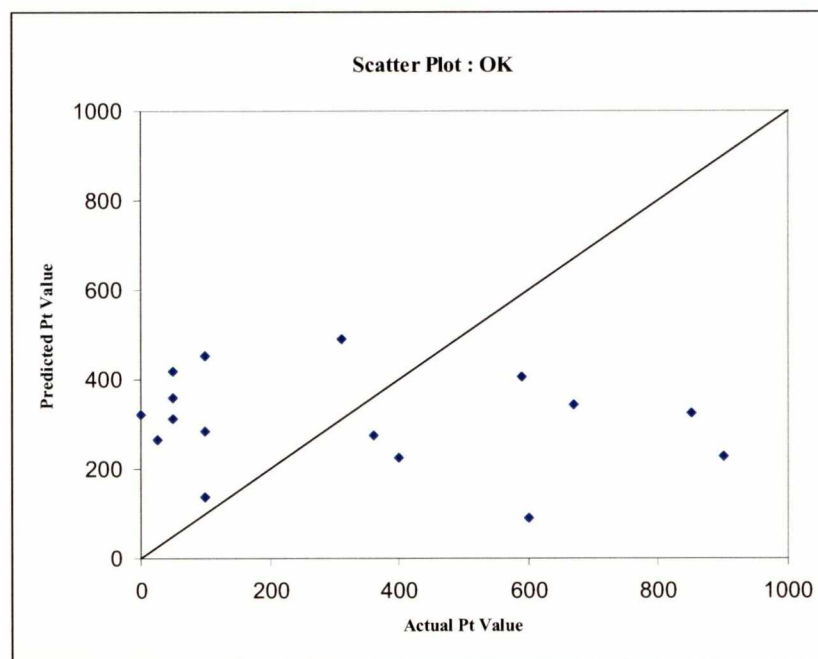


Figure 6.9: Scatter plot for the OK model testing data for platinum. The x-axis represents the actual data versus the predicted data on the y-axis.

6.3.1.6 Ordinary Cokriging Between Platinum and Gold (CK-Pt-Au)

The advantage of cokriging is that it uses information from more than one variable, thus reducing the dimensionality issues to some extent. In this case, a cokriging between platinum and gold was used for prediction. The various parameters used for the CK-Pt-Au model are given in **Figure 6.10**. **Table 6.6** shows the performance measures obtained for the validation of the CK-Pt-Au model using the testing data. **Figure 6.11** shows the scatter plot for the predicted against the actual platinum values. The scatter plot indicates that the CK-Pt-Au model is able to approximate the median and the low values to some extent; however, it greatly under-predicts the high values.

Table 6.6: Performance measures for the CK-Pt-Au model obtained during the validation using the platinum data from inside the bay. The model was validated using a testing data (random split: 80% training and 20% testing).

<i>Method</i>	<i>RMSE</i>	<i>MAE</i>	<i>r</i>	<i>R²</i>	<i>E</i>
CK-Pt-Au	285.45	251.05	0.32	0.10	10.23

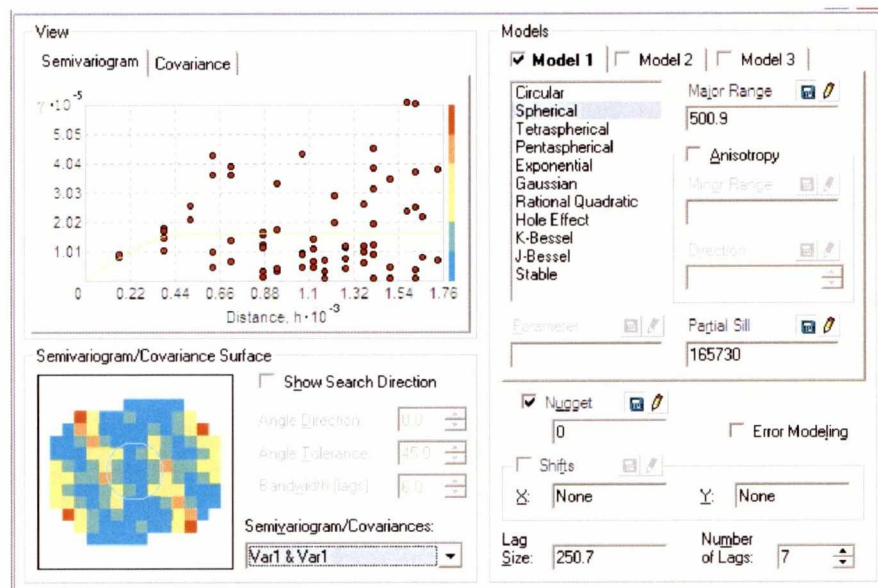


Figure 6.10: Parameters used for the CK-Pt-Au model for platinum data from inside the bay.

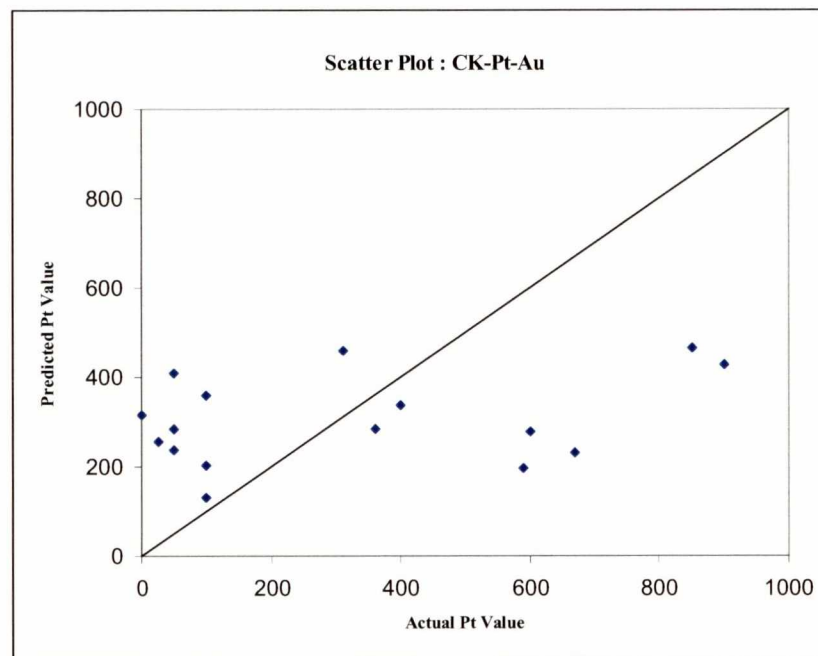


Figure 6.11: Scatter plot for the CK-Pt-Au model testing data for platinum. The x-axis represents the actual data versus the predicted data on the y-axis.

6.3.2 Comparison of Model Predictions

The performance of the different geostatistical models developed in Section 6.3.1 has been objectively compared to verify the model performance. **Table 6.7** summarizes the various performance measures and PI that are obtained for these different models using the testing data. **Table 6.7** also shows that the use of RBF provided the best model (lowest performance index number) for platinum distribution inside the bay. The analysis of correlation coefficients (**Table 6.7**) obtained using the various geostatistical methods revealed the highest value of 0.57 using RBF. The probable reason for this low correlation coefficient could be the limitation of the methods or the fact that the accumulation of marine platinum placers is a complex process influenced by underlying processes such as coastal currents sea-level transgressions. If these processes can be quantitatively incorporated in the model, the techniques might predict the marine placer distribution more efficiently. However, in most cases these underlying processes are not easily quantifiable.

A careful comparison of the different scatter plots received from the various geostatistical techniques (Section 6.3.1) reveal that some models are able to predict the median values more accurately, whereas some others better predict the high or the low values. It was evident from this observation that each model has its own advantages and limitations. A question ensued from this observation was: “Can the strengths of each of these models be captured to obtain an improved spatial distribution of platinum?”

Table 6.7: Performance measures and the performance indices obtained for the different models discussed in section 6.3.1 using the testing data.

Method	RMSE	MAE	r	R^2	E	PI
IDW	267.67	219.14	0.48	0.23	21.07	346.6
GPI	464.68	358.29	0.36	0.13	-137.86	702.54
LPI	448.49	351.35	0.37	0.14	-121.58	670.07
RBF	255.09	200.64	0.57	0.33	28.31	326.78
OK	337.03	295.72	-0.18	0.04	-25.13	462.16
CK-Pt-Au	285.45	251.05	0.32	0.10	10.23	375.22

There are several approaches such as ensemble models (hybrid models) where the output of the several individual techniques are combined using some form of multiple linear regression to obtain the final outputs (e.g., Hansen and Salamon, 1990; Perrone and Cooper, 1993; Jacobs, 1995; Dutta et al., 2006b). However, the ensemble models did not increase the model performance significantly (Dutta et al., 2006b). In the case of data classification problems, there have been several approaches to combine classifiers (outputs of individual classifiers), which have provided improved performance [e.g., ensemble classifiers (Drucker, 1994), multiple classifier system (Kittler et al., 1998; Fumera and Roli, 2005), mixture of experts (Gutta, 2000), committees of neural networks (Chee and Harrison, 2003), neuro-fuzzy fusion (Meher et al., 2006) etc.]. These classifier combinations are very popular, and are considered to be one of the most promising current research directions in pattern recognition and machine learning (Kittler and Roli,

2001; Kuncheva, 2004). MRPRT uses fundamentally similar approach and was inspired by the above techniques.

The study of these methods motivated the development of a new approach called the Multiple Regressive Pattern Recognition Technique (MRPRT). MRPRT uses a radial basis kernel SVR pattern learning algorithm available in the e1071 and kernlab package of the R-programming language (Vapnik, 1995; Kecman, 2000, Hastie et al., 2001; Karatzoglou et al., 2004; Meyer, 2006) for pattern recognition. Instead of using the latitude and longitude, which were used for the geostatistical techniques to train and develop the model, the MRPRT method uses the output from each of the geostatistical techniques as the input.

6.3.3 Multiple Regressive Pattern Recognition Technique

The basic principle of the MRPRT is explained using the scatter plot shown in **Figure 6.12**. The x and y axis of the scatter plot represent the actual and predicted values of three models (individual regression techniques). The performance measures of these three models are given in **Table 6.8**. It is observed (**Figure 6.12 & Table 6.8**) that all three models have poor predictability. However, it is learnt from **Figure 6.12** that model-1 is able to predict the low values accurately, model-2 the median values and model-3 the high values. Now the question is how could the accurate prediction of these different models be captured into a single model? In order to achieve this, a pattern recognition technique was used, where the technique would learn from the output of the three models. For the low values it would learn from model-1, for the median values from model-2 and

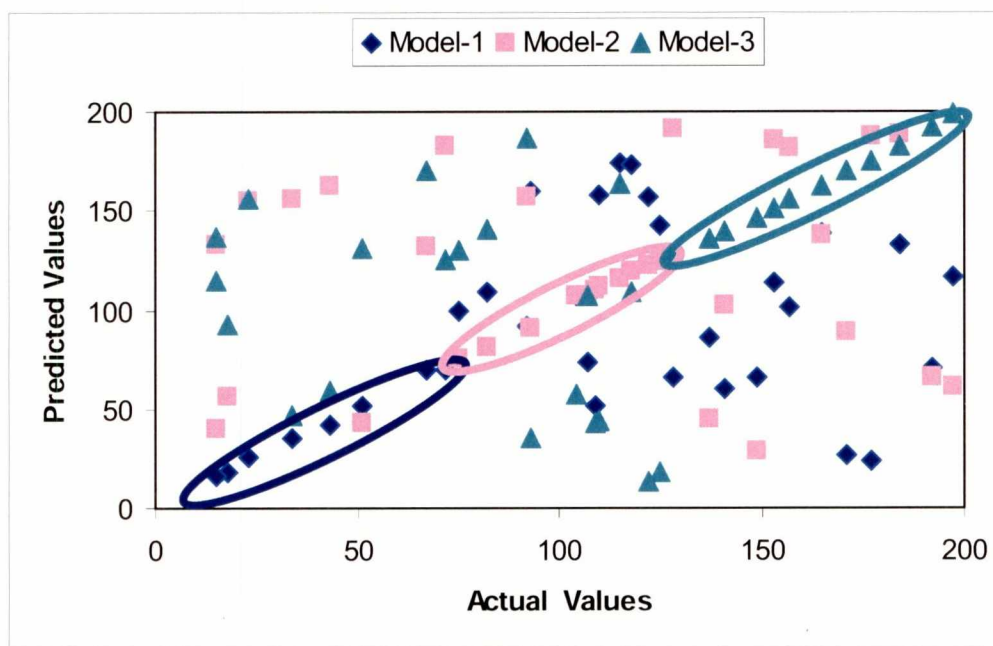


Figure 6.12: Scatter plot showing the Actual vs Predicted values for three hypothetical datasets represented as models 1, 2 & 3. It is observed that model-1 predicts the low values accurately, model-2 the median and model-3 the high values.

Table 6.8: Table showing the R^2 values obtained for models 1, 2 & 3 shown in Figure 6.12.

Method	R^2
<i>Model-1</i>	<i>0.28</i>
<i>Model-2</i>	<i>0.09</i>
<i>Model-3</i>	<i>0.10</i>

for the high values from model-3. This principle was used to develop the MRPRT model for Goodnews Bay data.

The philosophy used for the MRPRT approach to model the Goodnews Bay data is summarized below:

1. Six input variables were used for the final prediction using the MRPRT model. These input variables were the predicted platinum values using IDW, GPI, LPI, RBF, OK and CK-Pt-Au.
2. The same 80% of the predicted data from the individual regression models (e.g., IDW, GPI, LPI, RBF, OK and CK-Pt-Au) were used for training and the remaining 20% for testing.
3. The training data together with the corresponding actual platinum values were used to train and obtain the optimal SVR parameters.
4. The set of variables that gave the lowest RMSE value was used as the pattern recognition model to test the predictability of the remaining 20% of the data.
5. A radial basis kernel SVR pattern learning algorithm (Hastie et al., 2001) was used for the MRPRT analysis.
6. The performance measures of the model were calculated using the predicted platinum values by MRPRT and the corresponding actual values.

The **Table 6.9** shows the performance measures and the performance index obtained for the validation of the MRPRT model using the testing data. **Figure 6.13** shows the scatter plot for the predicted against the actual platinum values. **Figure 6.14**

shows a comparative map of the actual and the predicted platinum value using MRPRT. The scatter plot also indicates that MRPRT is able to predict the low, median and high values reliably. A comparison of the results from the MRPRT model (**Table 6.9**) to the results from individual geostatistical techniques (**Table 6.7**) revealed that the MRPRT approach is able to provide a significantly improved prediction of platinum inside the bay. It was also found that the r has improved from 0.57 (RBF) to 0.87 (MRPRT), the coefficient of efficiency from 28.31 (RBF) to 69.18 (MRPRT) and the performance index from 326.78 (RBF) to 198.06 (MRPRT), suggesting that MRPRT can be a pragmatic approach to model problems involving complex processes that cannot be quantified.

Colinearity and redundancy of the input variables could be a potential limitation to the MRPRT, viz., one or more of the variables used may not contribute to the prediction. The method for assessing the contribution of each input variable is left for future research. Such limitations, however, have been resolved in the past, with other methods, (Wolpert, 1992; Cao, 1995). According to D. Thomas (personal communication, December 18, 2006), “using multiple variables will always increase prediction, even if additional variables are random noise. Thus, when comparing MRPRT to spatial models, one cannot make a clear comparison”. The evaluation of this statement is also left for future research. Also, the predicted values used as input variables have error associated with them that has not been accounted for in MRPRT.

Table 6.9: Performance measures for the MRPRT model obtained during validation, using the testing data. The performance index is also provided

<i>Method</i>	<i>RMSE</i>	<i>MAE</i>	<i>r</i>	<i>R</i> ²	<i>E</i>	<i>PI</i>
<i>MRPRT</i>	<i>167.24</i>	<i>138.06</i>	<i>0.87</i>	<i>0.76</i>	<i>69.18</i>	<i>198.06</i>

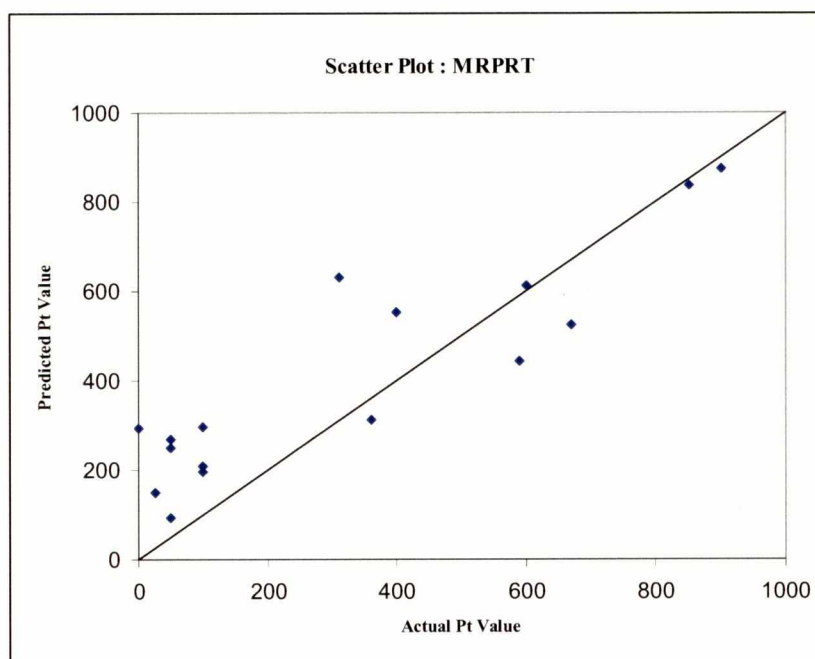


Figure 6.13: Scatter plot for the MRPRT model testing data for platinum values from inside the bay. The x-axis represents the actual data, versus the predicted data on the y-axis.

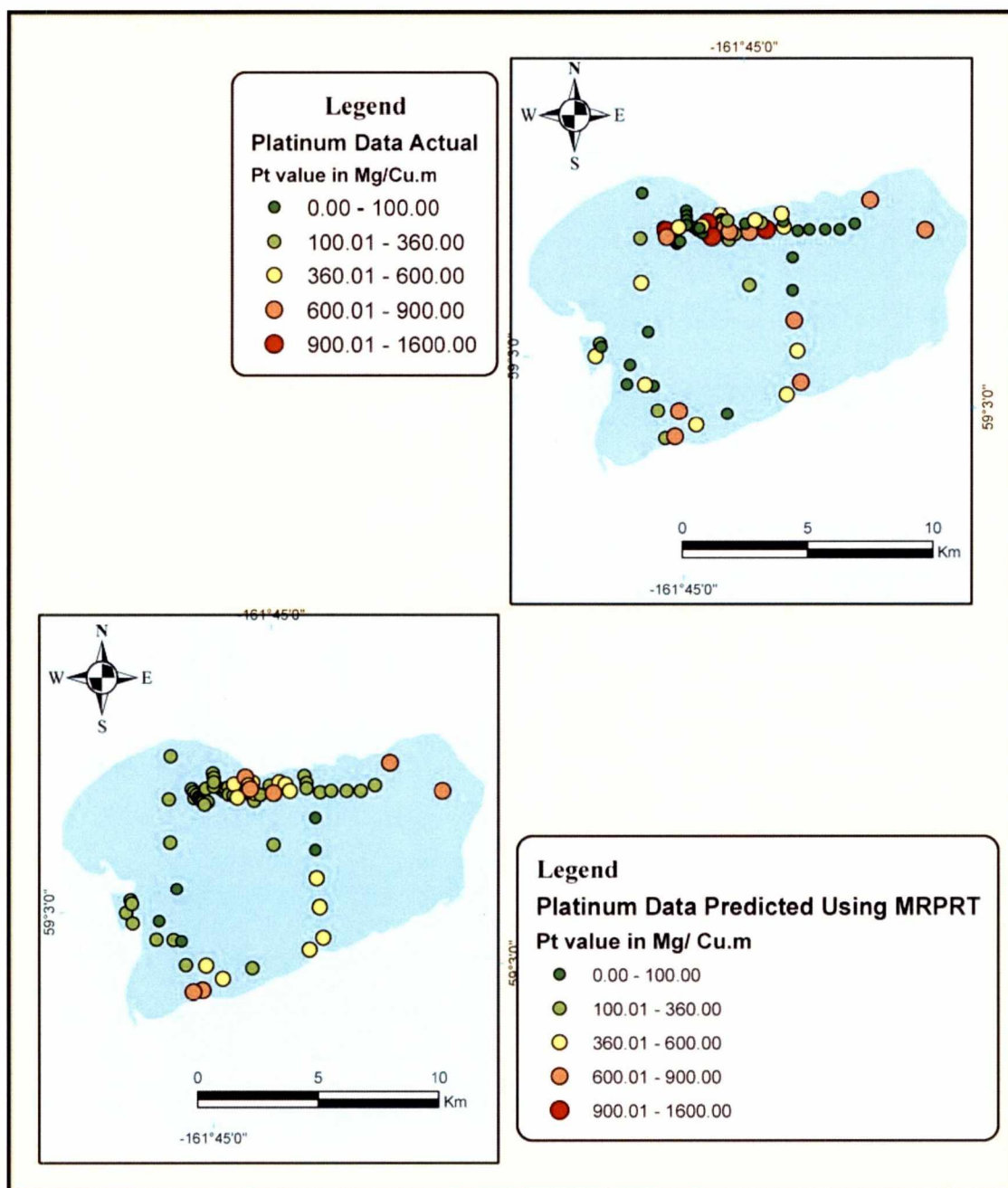


Figure 6.14: Comparison of the actual vs predicted platinum values using MRPRT approach.

6.4 ANALYSIS OF THE PLATINUM DISTRIBUTION OUTSIDE GOODNEWS BAY

The platinum data outside the bay comprised 400 data points. These points were randomly split into training and testing datasets with 80% of the data (320 data points) belonging to the training set, and the remaining 20% (80 data points) to the testing set. The data from outside the bay were analyzed twice, with and without incorporating the loss factor (loss factor discussed in Section 5.4.1). The analysis without incorporating the loss factor will be known as analysis outside bay-1 and incorporating the loss factor will be known as analysis outside bay-2.

The data from outside the bay were analyzed for the distribution of platinum following a similar approach to that used for analyzing the distribution of platinum data from inside the bay. The performance measures and PI of the outside bay data are discussed in the following sections.

6.4.1 Analysis Using Geostatistical Techniques

The platinum data from outside Goodnews Bay were analyzed using various geostatistical and pattern recognition techniques discussed in Section 6.3.1. The modeling parameters and the scatter plots of the testing data for each of these methods of analyzing outside bay-1 and outside bay-2 platinum data are provided in Appendices D and E respectively. **Tables 6.10 and 6.11** summarize the performance measures and performance indices obtained using the testing data.

Table 6.10: Outside Bay-1 summary of the various performance measures and performance indices obtained for the different geostatistical models for testing data.

Method	RMSE	MAE	r	R^2	E	PI
IDW	172.97	105.41	0.5361	0.2874	13.76	259.21
GPI	161.86	117.34	0.5213	0.2718	24.48	237.38
LPI	168.28	121.72	0.4636	0.2149	18.38	249.9
RBF	159.03	108.12	0.5512	0.3039	27.11	231.92
OK	163.58	114.55	0.5006	0.2506	22.87	240.71
CK-Pt-Au	178.15	114.74	0.4868	0.2369	8.52	269.63

Table 6.11: Outside Bay-2 summary of the various performance measures and performance index obtained for the different geostatistical models for testing data.

Method	RMSE	MAE	r	R^2	E	PI
IDW	159.25	107.05	0.5448	0.2968	26.50	232.75
GPI	168.77	122.30	0.4560	0.2079	17.46	251.31
LPI	168.42	122.07	0.4590	0.2107	17.80	250.62
RBF	159.85	109.24	0.5416	0.2933	25.95	233.9
OK	163.24	118.61	0.5296	0.2805	22.78	240.46
CK-Pt-Au	178.36	115.58	0.4821	0.2324	7.81	270.55

Tables 6.10 and 6.11 indicate that in case of analyzing outside bay-1 and 2 data, the RBF model performed better than the other geostatistical techniques. The performance measures, RMSE and MAE, are minimal for the RBF model. It also has the maximum correlation coefficients and coefficient of efficiency. The performance index for the RBF model is the least, ranking it to be the best model among the various geostatistical techniques used to analyze the distribution of platinum outside Goodnews Bay.

The RBF model, without incorporating the loss factor, performed slightly better than the RBF model incorporating the loss. However, the improvement in the prediction was negligible. The data from outside Goodnews Bay were also analyzed using the MRPRT approach to check whether it could improve the predictions.

6.4.2 Analysis Using Multiple Regressive Pattern Recognition Technique

6.4.2.1 Outside Bay Data-1

For the MRPRT approach to analyzing the inside bay data, using the outputs of all six methods (IDW, GPI, LPI, RBF, OK and CK-Au-Pt,) as the input variable gave the best prediction. However, for the outside bay data-1, it was found that using the outputs from IDW and RBF as the input variables gave the best performance. **Table 6.12** shows the performance measures and the performance indices obtained for the validation of MRPRT model using the testing data. Comparing **Tables 6.12 and 6.10**, it was observed that the model developed using the MRPRT performed better than all other geostatistical

Table 6.12: Outside Bay-1 summary of the various performance measures for the MRPRT model using the testing data.

<i>Method</i>	<i>RMSE</i>	<i>MAE</i>	<i>r</i>	<i>R</i> ²	<i>E</i>	<i>PI</i>
<i>MRPRT</i>	152.59	87.37	0.6122	0.3748	32.88	219.71

techniques. MRPRT has the least RMSE and MAE; and moreover it has the maximum correlation coefficients and coefficient of efficiency. The performance index is also least for the MRPRT. **Figure 6.15** shows the comparison of the actual vs. predicted values for platinum using the MRPRT model for outside the bay data-1.

6.4.2.2 Outside Bay Data-2

In the case of the outside bay data-2, several combinations of the input variables were used to verify predictability of the MRPRT model. It was recognized that, similar to the inside bay data, using the outputs of all the six methods (IDW, GPI, LPI, RBF, OK and CK-Au-Pt) gave the best performance measures. **Table 6.13** shows the performance measures and performance indices obtained for the validation of the MRPRT model using the testing data. Comparing the performance of the MRPRT with the other geostatistical techniques discussed in **Table 6.11**, the MRPRT also gave a better predictability. The comparison of the actual vs. predicted values using the MRPRT model for platinum outside the bay data-2 is given in **Figure 6.16**.

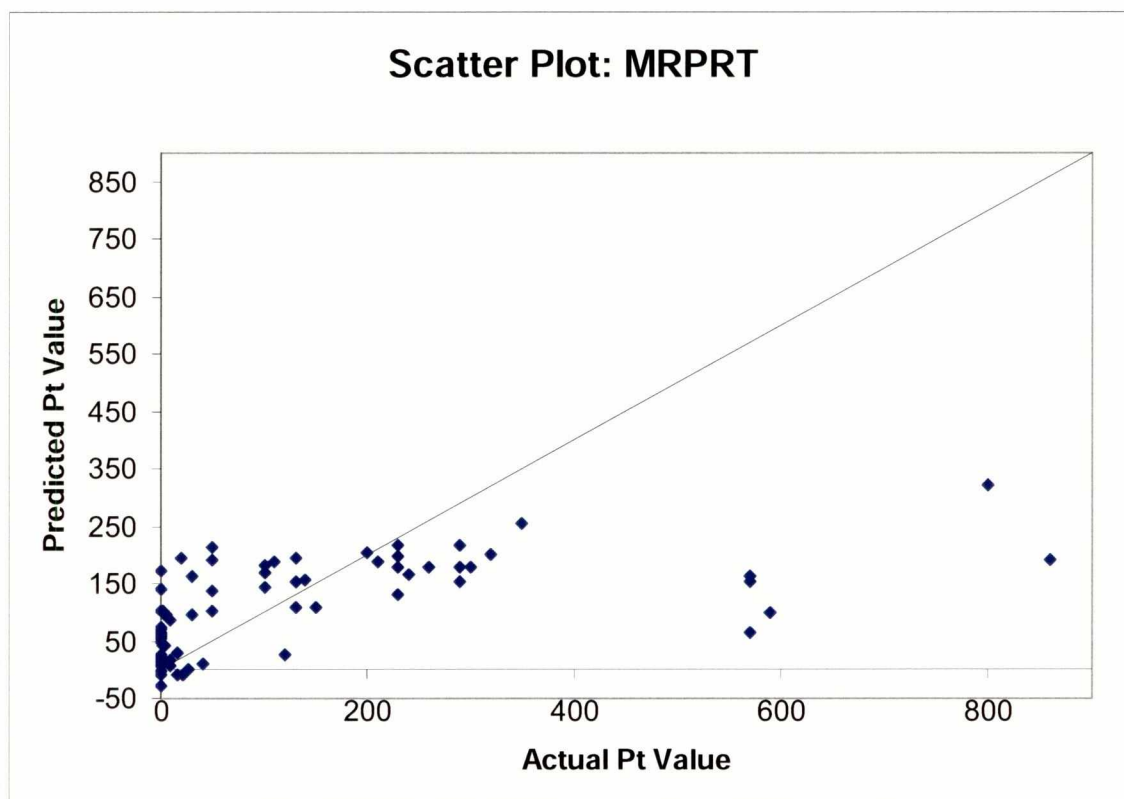


Figure 6.15: Scatter plot for the MRPRT outside bay-1 model for platinum values. The x-axis represents the actual data versus the predicted data on the y-axis.

Table 6.13: Outside Bay-2 summary of the various performance measures for the MRPRT model using the testing data.

<i>Method</i>	<i>RMSE</i>	<i>MAE</i>	<i>r</i>	<i>R²</i>	<i>E</i>	<i>PI</i>
<i>MRPRT</i>	<i>155.86</i>	<i>96.15</i>	<i>0.5630</i>	<i>0.3169</i>	<i>30.05</i>	<i>225.81</i>

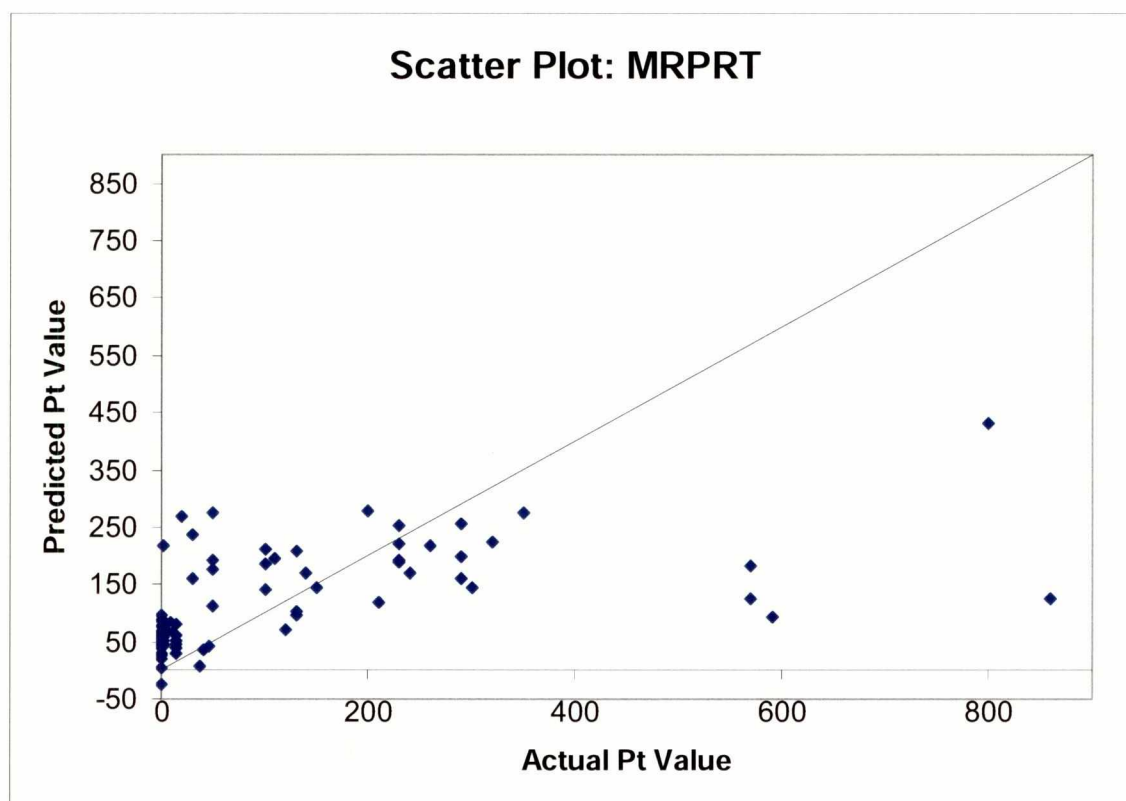


Figure 6.16: Scatter plot for the MRPRT outside bay-2 model for platinum values. The x-axis represents the actual data, versus the predicted data on the y-axis.

6.5 SYNTHESIS OF RESULTS

The models developed for the prediction of platinum inside and outside the bay were combined to develop the prediction map for the entire study area. Sections 6.3 and 6.4 show that for platinum data both inside and outside the bay, the MRPRT model gave the best performance when validated using an independent testing dataset

In order to develop the spatial distribution map for the entire study area using MRPRT, assuming a grid size of 40.87m x 40.87m (default used by ArcGIS) would yield 2.9 million data points. However, the algorithm in the e1071 package only allows 27000 data points. Therefore, developing a prediction map using MRPRT was not possible without developing a new code that could run on the entire dataset. Hence as an alternative, the comprehensive distribution was developed using RBF, which was the best model for both inside and outside the bay data.

The platinum distribution map for the study area developed using the data from inside the bay and outside bay data-1 (without loss factor) is given in **Figure 6.17**.

Figure 6.18 shows the distribution map for the study area using data from inside the bay and outside bay data-2 (with loss factor). A comparison study of **Figures 6.17 & 6.18** revealed that there was no significant change in the distribution pattern of platinum caused by incorporating the loss factor.

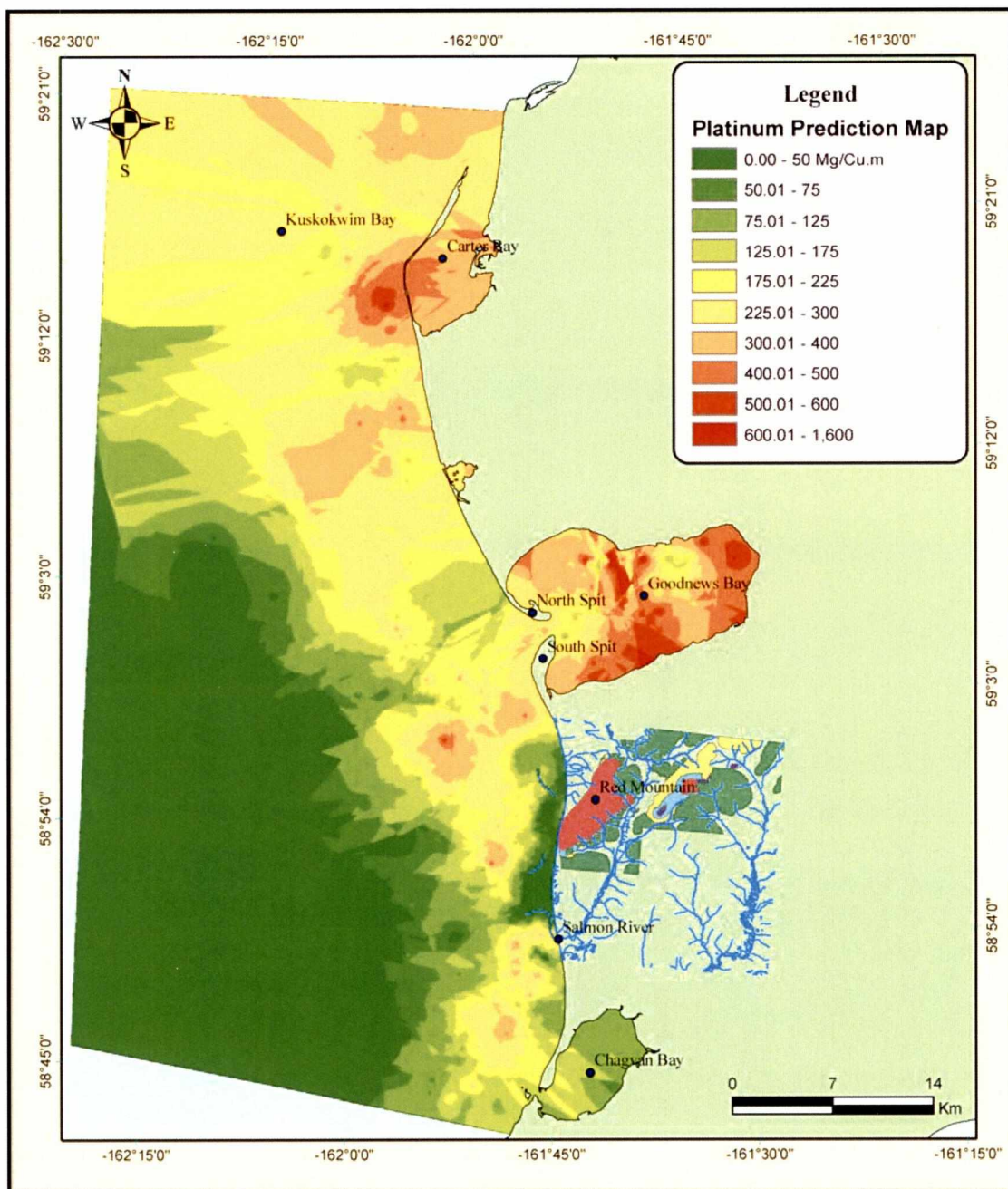


Figure 6.17: Map showing the distribution of platinum in the study area using inside bay data and outside bay data-1.

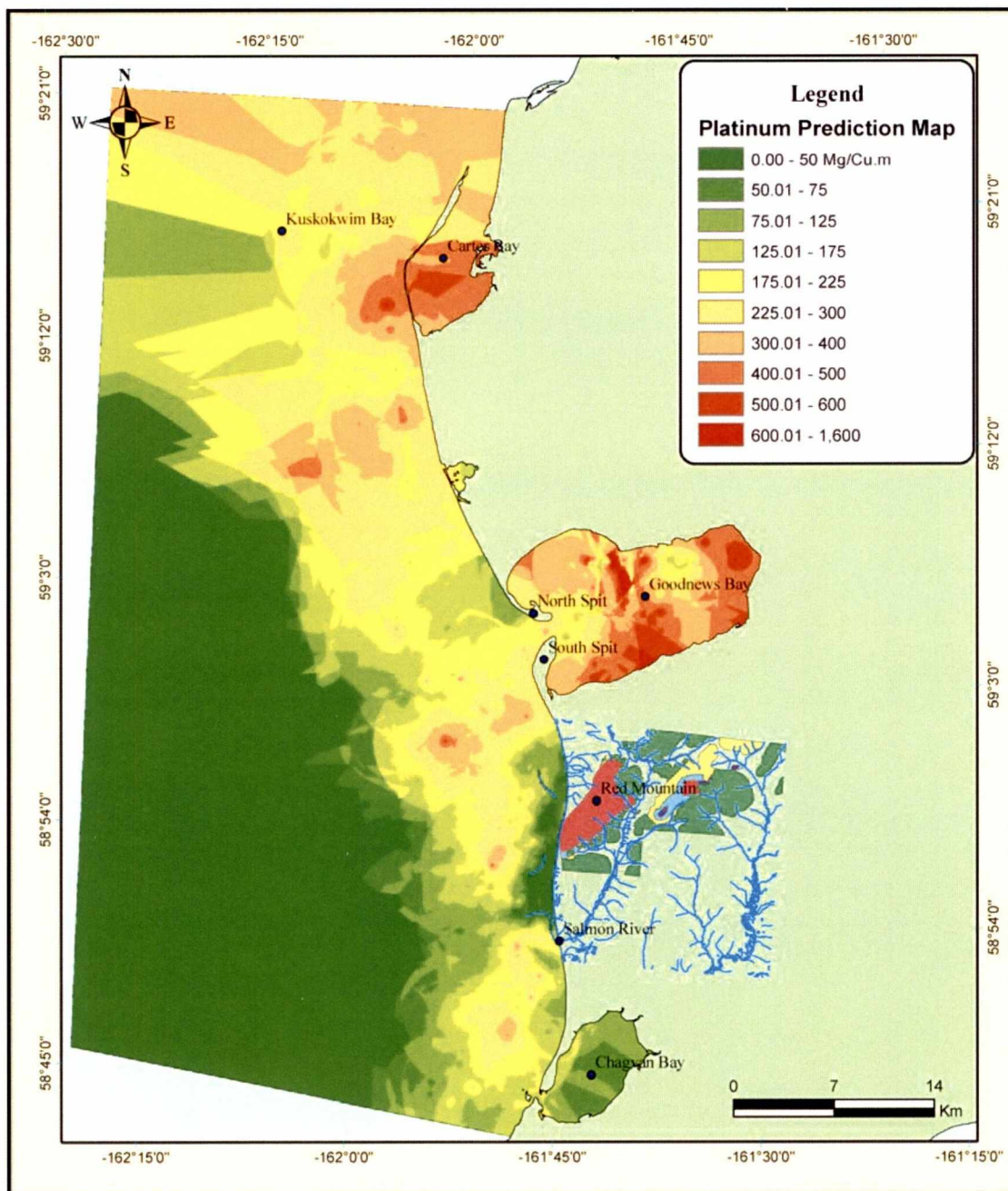


Figure 6.18: Map showing the distribution of platinum in the study area using inside bay data and outside bay data-2.

A careful examination of the distribution of platinum in the study area (**Figure 6.17**) shows two locations of promising potential for platinum. These are areas inside Goodnews Bay and locations near Carter Bay.

Additionally, the platinum prediction map was compared with the geospatial occurrence of different features in the region, such as coastal current direction, sand bars and possible paleochannels, to assess the influence of these features on the depositional pattern of platinum.

Figure 6.19 shows the spatial distribution of platinum compared with the coastal current direction. The coastal current direction map suggests that there is a movement of current into the bay and this might be causing the high concentration of platinum deposition inside the bay. However, the net coastal current movement in this region is towards the north as evidenced by south spit being wider than the north spit. It is also observed that there is an eddy current formation in the Carter Bay region. These observations suggest that the high platinum concentrations near the Carter Bay region are derived from the net coastal current movement and deposited there due to eddy current formation.

Figure 6.19 shows that there is a split in the direction of the coastal current due to Flat Cape, a headland located south of Red Mountain. The prediction map also shows a similar trend in the depositional pattern of platinum, which is elevated on either side of Flat Cape. The high concentration of platinum in low energy environments such as

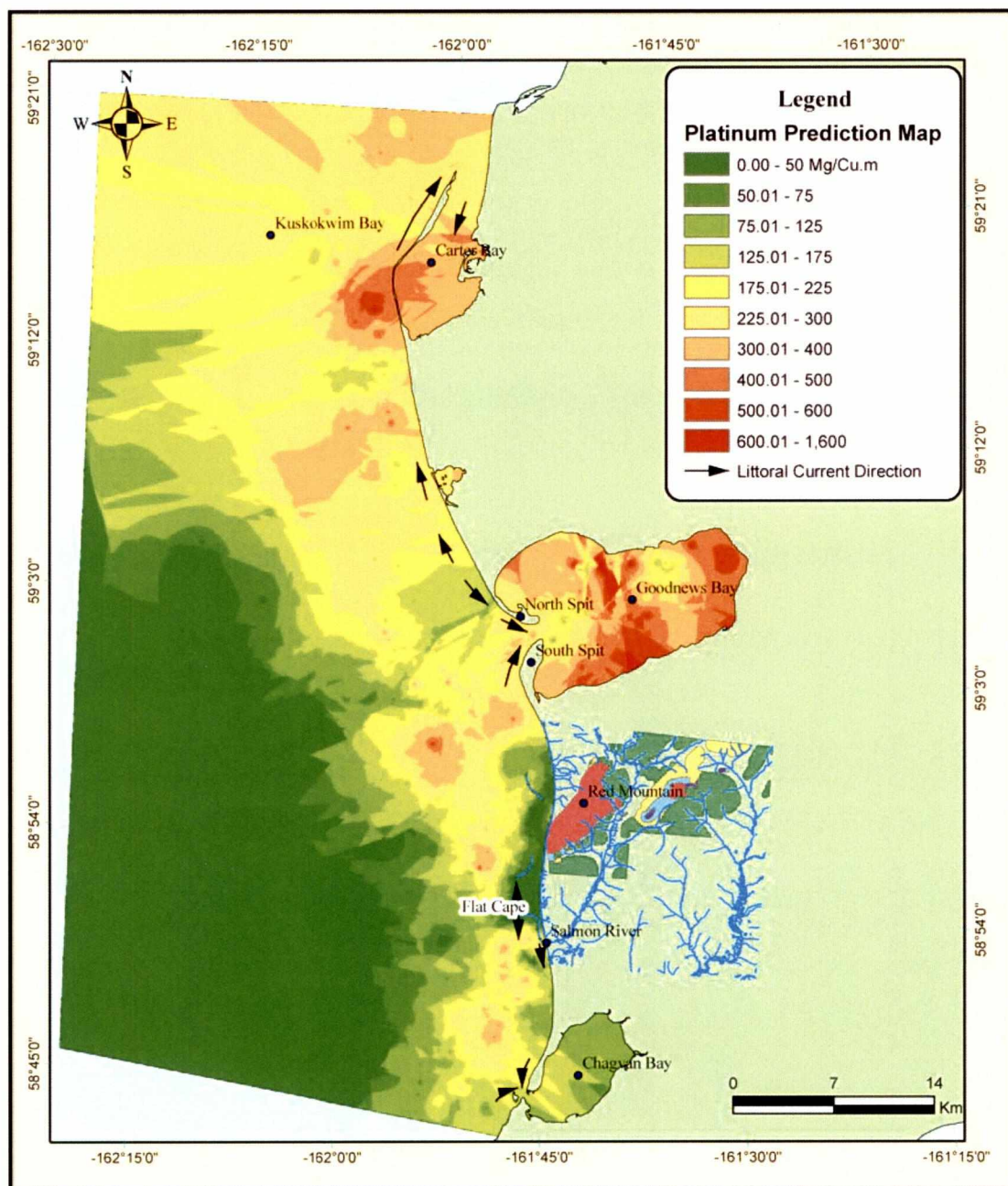


Figure 6.19: Comparison between the distribution of platinum and coastal currents in the study area.

Goodnews Bay and Carter Bay and the depositional pattern seen near Flat Cape suggest that the deposition of platinum in the study area is strongly influenced by the coastal currents.

The spatial distribution of platinum was then compared to the paleochannels as shown in **Figure 6.20** to assess whether these channels had any significant correlation to the deposition of platinum. However, **Figure 6.20** shows no particular correlation between platinum distribution and the location of paleochannels. The probable reason for this is that the seismic data analysis in Section 5.2.2 had found the bottom of these channels to be 20-40m deep. In addition, from the glacial history (Section 2.4) it is seen that the entire study area was glaciated at least once. Certainly, these channels could be covered with glacial material and modern sediments, which could be the reason why no significant correlation is found in the comparison of these channels to the surficial platinum distribution map.

The next step was to develop a combined map of the platinum distribution and the sand bars observed in the study area is shown in **Figure 6.21**. It was hypothesized that if these sand bars represent paleobeaches, there could be lag deposits of platinum due to sea level transgression. **Figure 6.21** illustrates that, out of the four sand bars identified, the one in the north closer to the shoreline shows some promising platinum deposits. The other three do not show sufficient evidence for lag deposits. This could be because of insufficient data from areas close to these sand bars or burying of the lag deposits by modern processes.

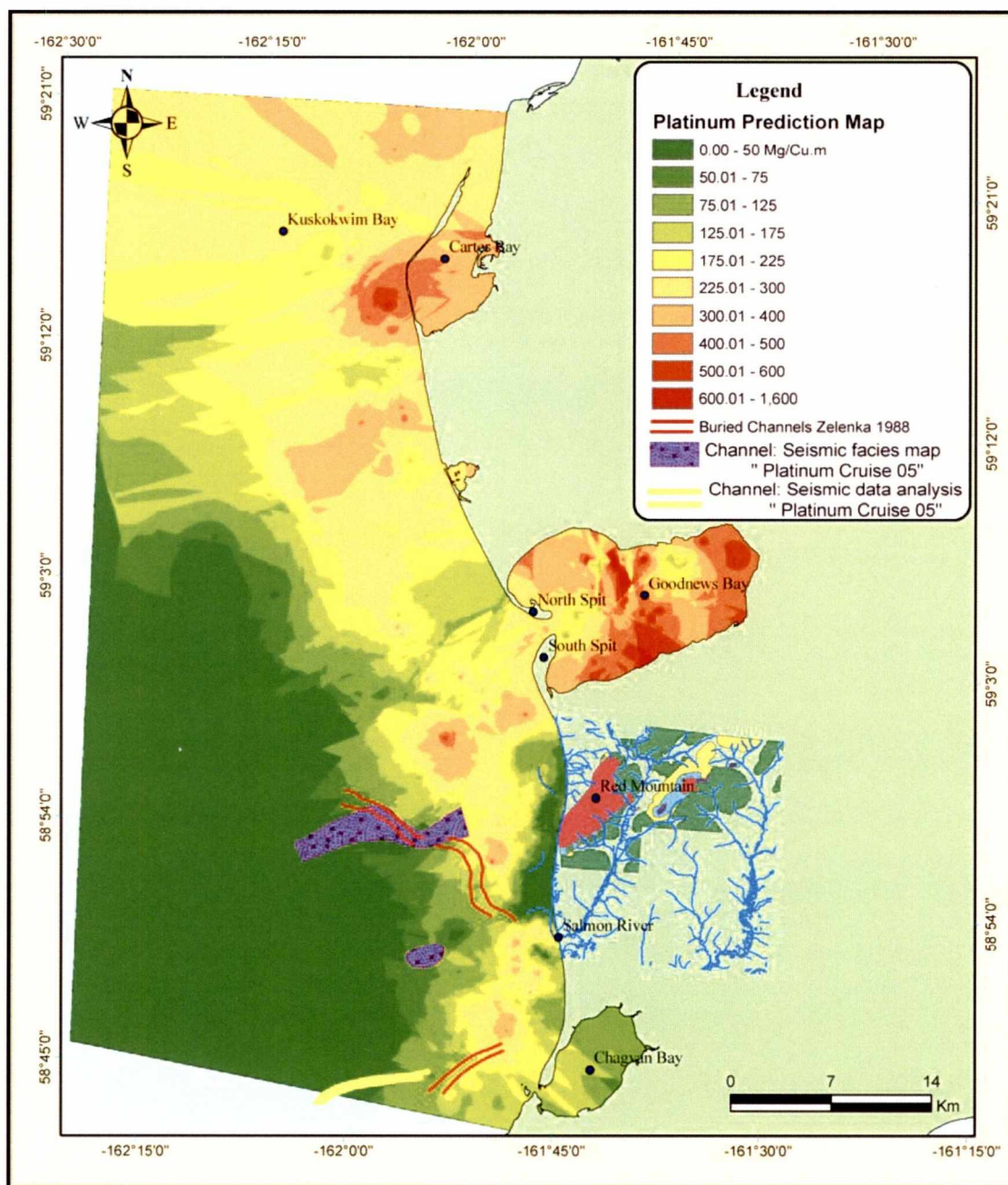


Figure 6.20: Comparison between the distribution of platinum and the paleo-channels in the study area.

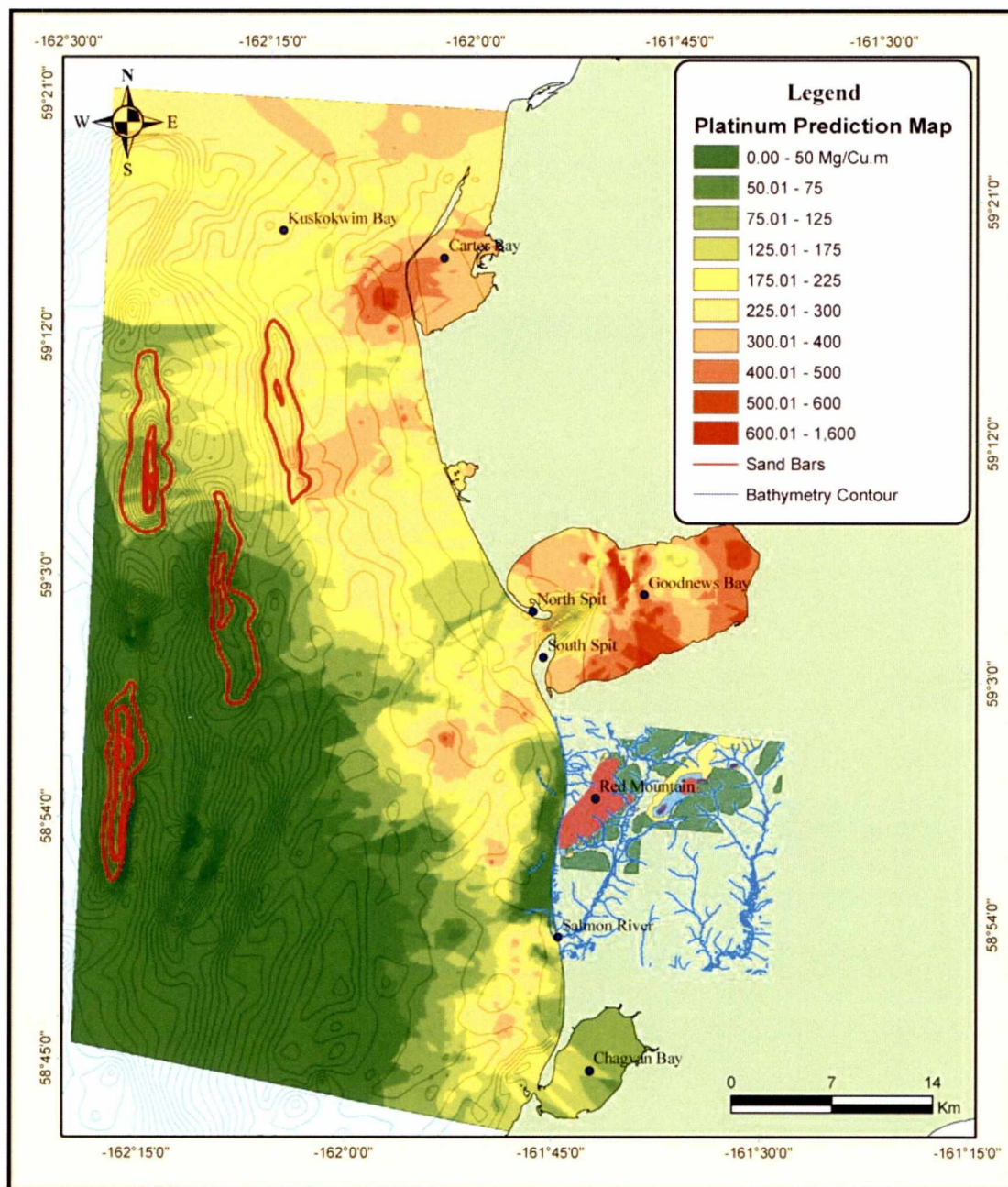


Figure 6.21: Comparison between the distribution of platinum and the sand bars (probable paleo-beaches) in the study area.

7.0 CONCLUSIONS AND FUTURE WORK

In order to assess the offshore platinum potential, a geodatabase was developed by compiling and integrating data from geophysical and geochemical explorations carried out by different organizations at Goodnews Bay. The analysis of the data compiled in the geodatabase was divided into geophysical exploration, image analysis and platinum distribution analysis. There were three research hypotheses developed for this study.

The first hypothesis was that offshore region of Goodnews Bay would have buried channels and drowned ultramafic rocks, the former being extensions of Salmon River and its tributaries or channels that drain buried/drowned ultramafic rocks. The analysis of the geophysical data (both seismic and magnetic) identified possible ultramafic rock and two paleochannels in the study area. The locations of these channels were promising. One channel was near the ultramafic rock and the other one was a possible extension of the ancient analog of the Salmon River, buried by glaciation, suggesting a strong potential for buried alluvial placer platinum.

The second hypothesis was that the sand bars identified in the study area would have concentrated the heavy minerals as lag deposits, during the transgressive cycles of the sea level fluctuation. In order to test this hypothesis, the platinum distribution map was compared to the position of the sand bars. Out of the four sand bars identified in the study area, lag deposits were found near one, which was located in the nearshore region. The reason for not finding lag deposits in the other sand bars could be due to insufficient data from regions farther offshore and the modern processes burying these lag deposits.

The third hypothesis was that the platinum deposits in the offshore region would be undergoing chemical weathering and these weathered materials would get deposited in low energy environments heterologous to the placer deposits. From the analysis of the platinum prediction map it was found that the platinum concentration was considerably elevated in two locations in the study area. These two locations were areas proximal to Carter Bay and inside Goodnews Bay. A comparison of the platinum distribution to the sediment distribution in the area revealed that these locations are low energy environments. The reason for the high concentration of platinum in the low energy environment could be attributed to either the platinum in the study area being chemically weathered or being fine particulates (clay-silt size). In both these cases, the platinum could be transported by coastal currents to low energy environments heterologous to placer deposits which are found in high energy environments.

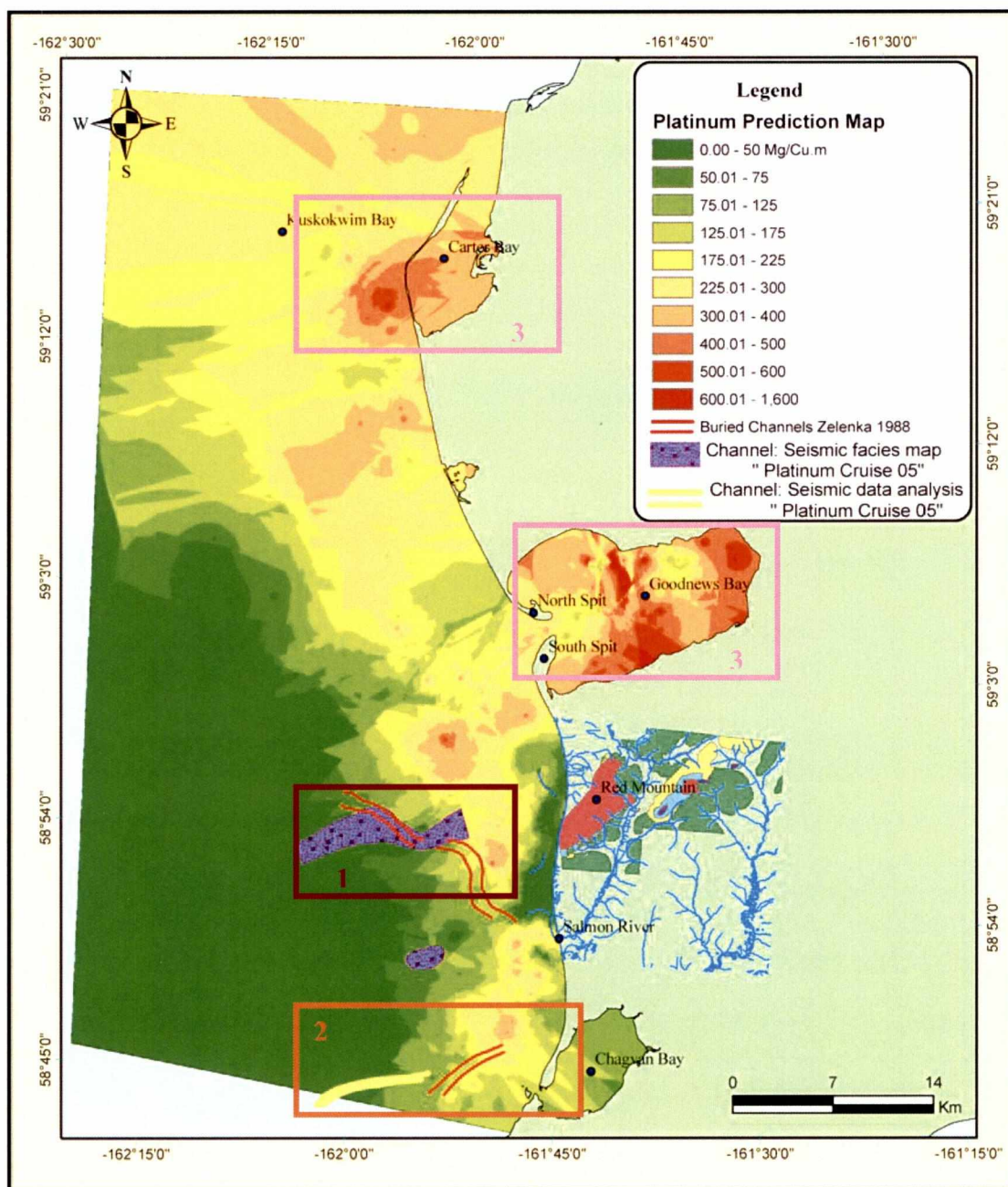
The platinum data available in the geodatabase were analyzed to assess the distribution of platinum in the study area using several geostatic and pattern recognition techniques. It was found that none of these techniques individually captured the distributional trend of platinum completely. This could be because the distribution of platinum in the study area has been influenced by complex underlying processes such as sea level transgression, modern processes and coastal currents. In most cases, it would be extremely difficult to quantify some of these underlying processes for development of the model. To overcome the modeling challenges posed by complex processes a new technique was employed that utilized the capability of SVR to learn patterns. This

approach is known as multiple regressive pattern recognition technique (MRPRT). The performance measures of the MRPRT demonstrated great potential in modeling complex processes.

The locations in the study area that need future work are identified in the map provided as **Figure 7.1**. The number shown on the map corresponds to the order in which future work is presented.

1. Collect samples from the bottom of the paleochannels to estimate the platinum values available in these locations.
2. Study the channel using geophysical data to reconstruct the buried topography and in turn its relationship with the buried Salmon River identified by Mertie (1940).
3. Analyze the archived half cores from the “Platinum Cruise 05” and collect more samples from Goodnews Bay and Carter Bay to study the extent of chemical weathering, deposition in low energy environments and the grain size distribution of platinum in this region.

The other recommendation for future work would be to develop a code for MRPRT, to overcome the limitations of the e1071 package in r language which restricts the number of data points that can be analyzed to 27000.



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Appendix A

“Platinum Cruise 05” details:

A.1: The vessel used for the cruise was the M/S Erin Lynn, shown below in the photograph.



A.2: Members of the cruise and their affiliations are given below.



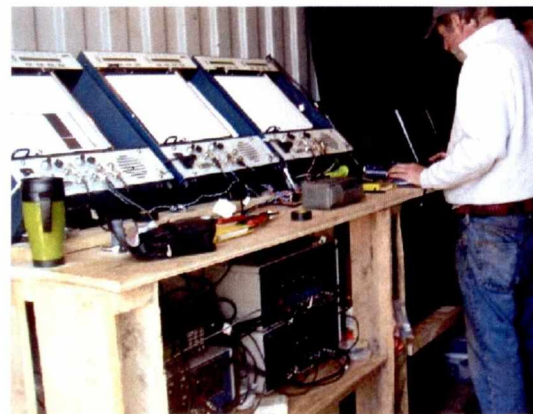
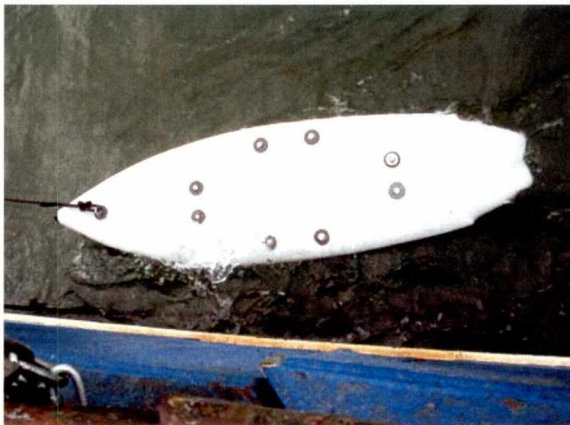
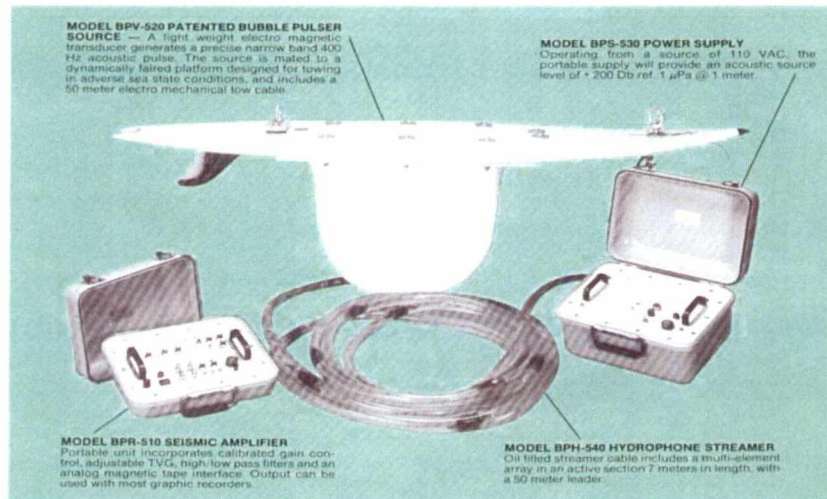
Front row (left to right): Alejandro Sarroca (Innerspace Exploration Team), Dick Sylwester (Golder Associates) *Back row (left to right):* Thomas Oommen (CEM/UAF), James C Barker (Consultant), Sathy Naidu (SFOS/UAF), Crayton Fenn (Innerspace Exploration Team), Dave Aldrich (Golder Associates), John J Kelley (SFOS/UAF).

A.3: Details of the marine magnetometer used for the “Platinum Cruise 05.”



A marine SeaSPY magnetometer was used to determine if bathymetric or subsurface geologic features contain magnetite, a heavy mineral often associated with the presence of platinum. The magnetic data were plotted in real time using a graphic recorder and were also stored in digital format for post-cruise processing.

A.4: Details of the seismic data instrumentation used for the “Platinum Cruise 05.”



The sub-bottom data were acquired with an applied acoustic engineering model seismic system and a Datasonic bubble pulser. The data were digitally received and stored on a Sony PC208 DAT recorder and displayed real-time on an EPC model 11086 thermal graphic recorder.

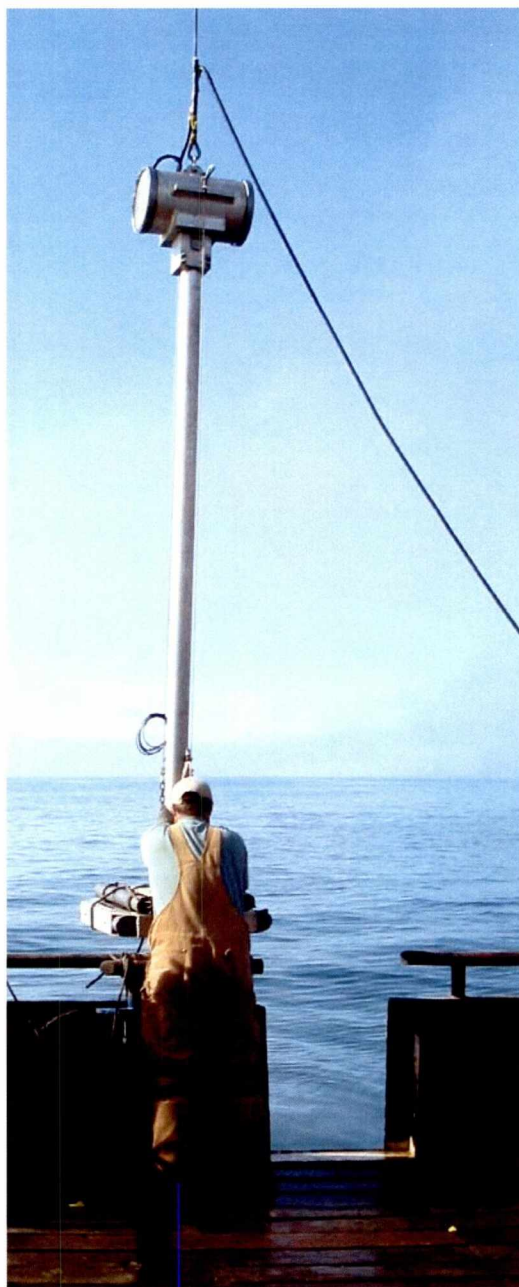
A.5: Details of the van veen grab sampler and sampling process.



A.6: Details of the pipe dredge sampler and sampling process.



A.7: Details of the vibracore sampler and sampling process.



Appendix B

Photographs of sediment sample preparation for platinum analysis. The samples were prepared at the Institute of Marine Science and Mineral Industries Research Lab at UAF. The different steps of the sample preparation are shown in **Figure 4.7**.



Figure B.1: Pipe dredge samples.



Figure B.2: Vibracore samples.



Figure B.3: Core cutting: Splitting of the vibracore sample.

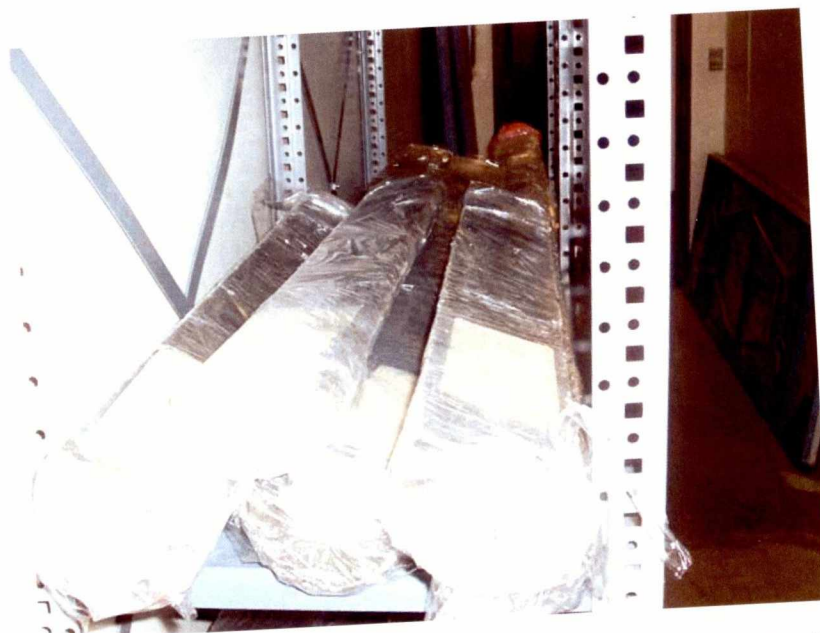


Figure B.4: Half split of the vibracore sample archived.

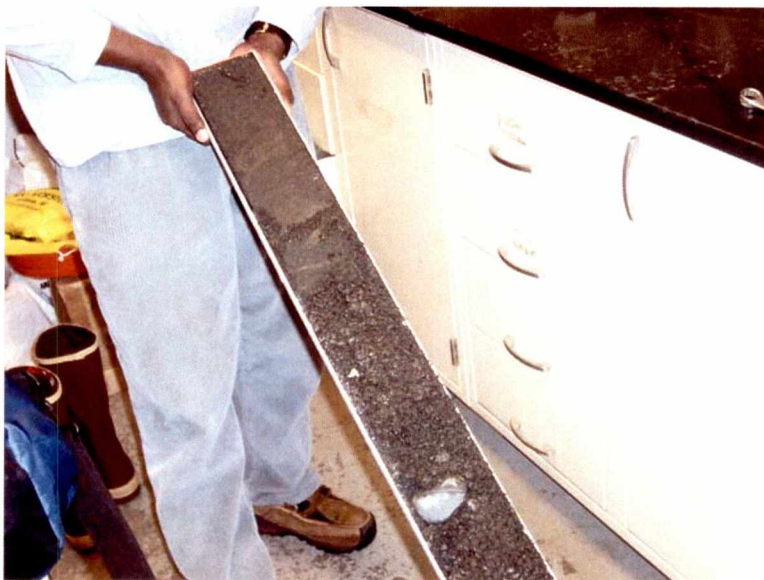


Figure B.5: Half split of the vibracore sample taken for analysis.



Figure B.6: Sample being wet sieved to remove clay.



Figure B.7: Sample being dried after wet sieving.



Figure B.8: Dry sieving using Ro-Tap apparatus to remove particle size > No.20 ASTM-E11 .



Figure B.9: Representative sample of 750-800gm for heavy mineral separation being obtained using a Jones Splitter.

Appendix C

Examples of seismic reflection data from “Platinum Cruise 05” for each sediment facies identified in **Figure 5.7**. (Source: Golder Associates Inc., Washington)

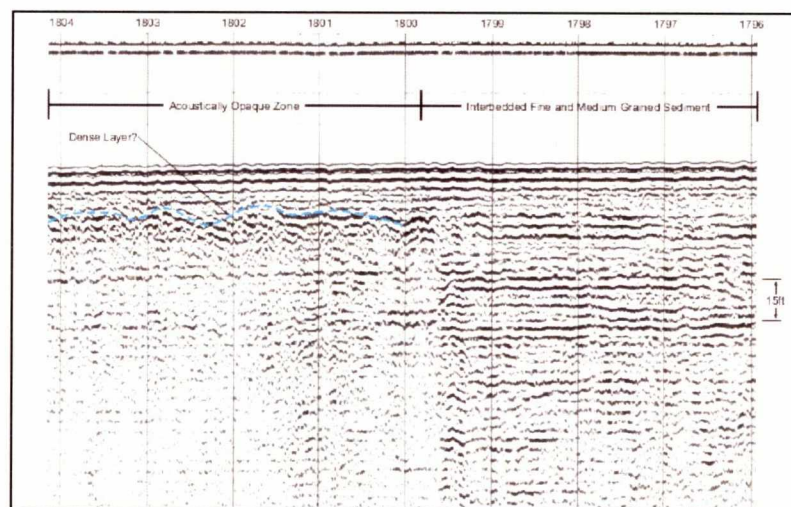


Figure C.1: Example of acoustically opaque and dense zone, and interbedded fine to medium grained sediment.

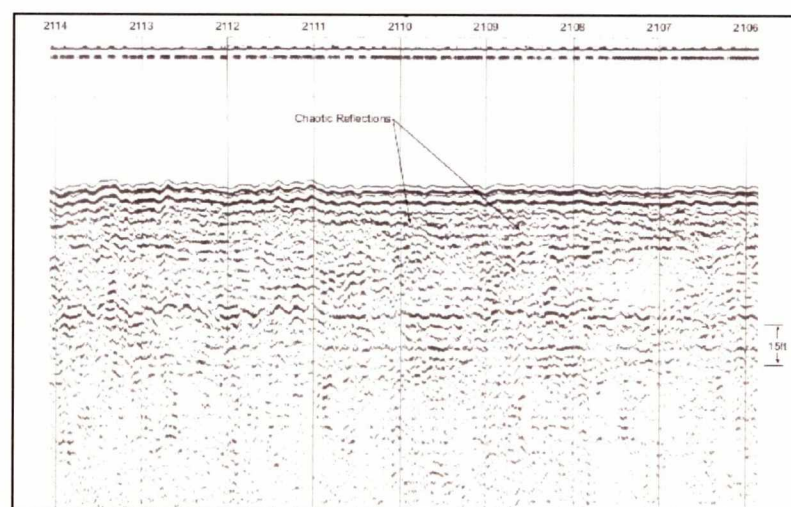


Figure C. 2: Example of chaotic seismic reflection.

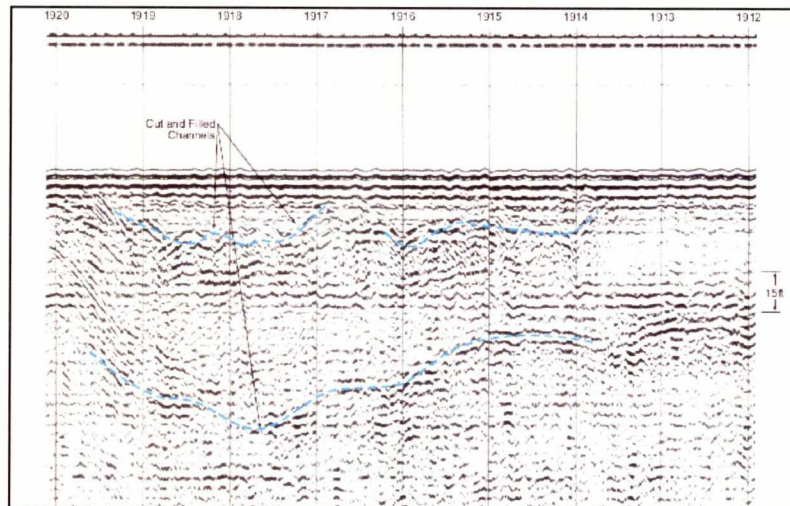


Figure C.3: Example of seismic reflection from cut and fill channel deposit.

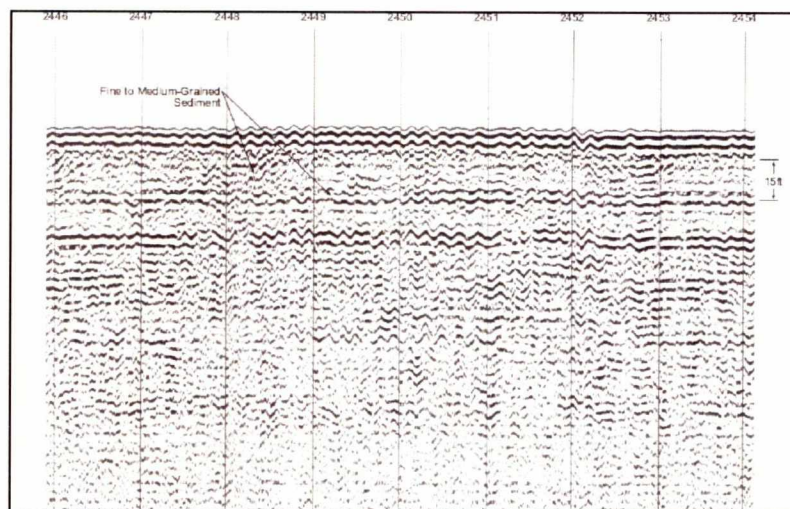


Figure C.4: Example of seismic reflection from fine to medium grained flat laying sediment deposit.

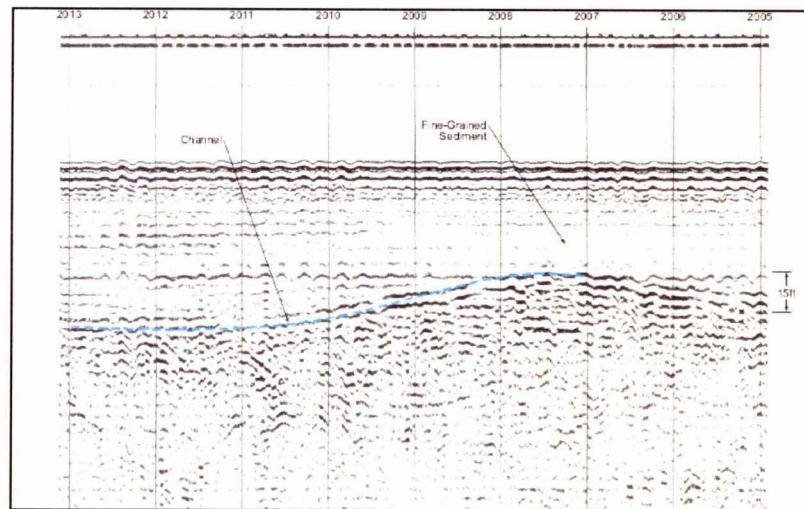


Figure C.5: Example of seismic reflection from channel and fine grained sediment deposit.

Appendix D

Modeling parameters and scatter plots outside bay-1

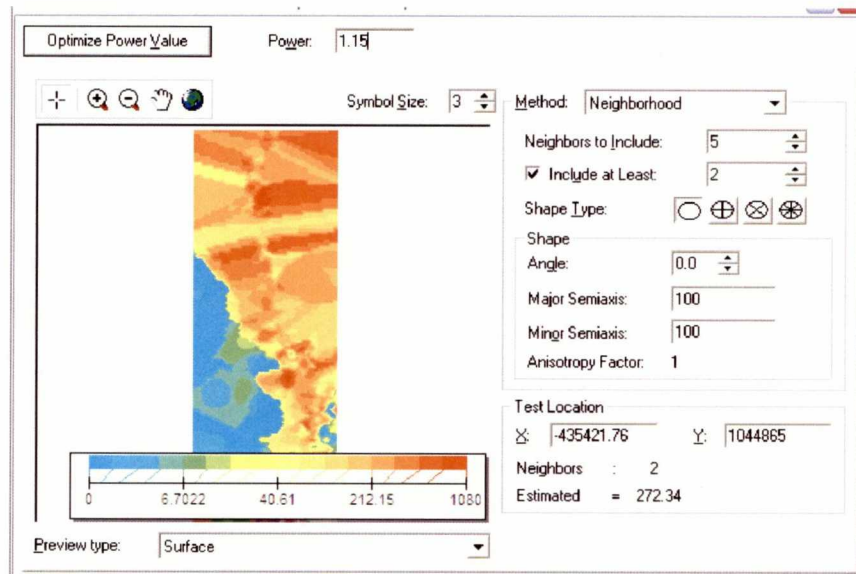


Figure D.1: Parameters used for the IDW model for platinum from outside the bay-1.

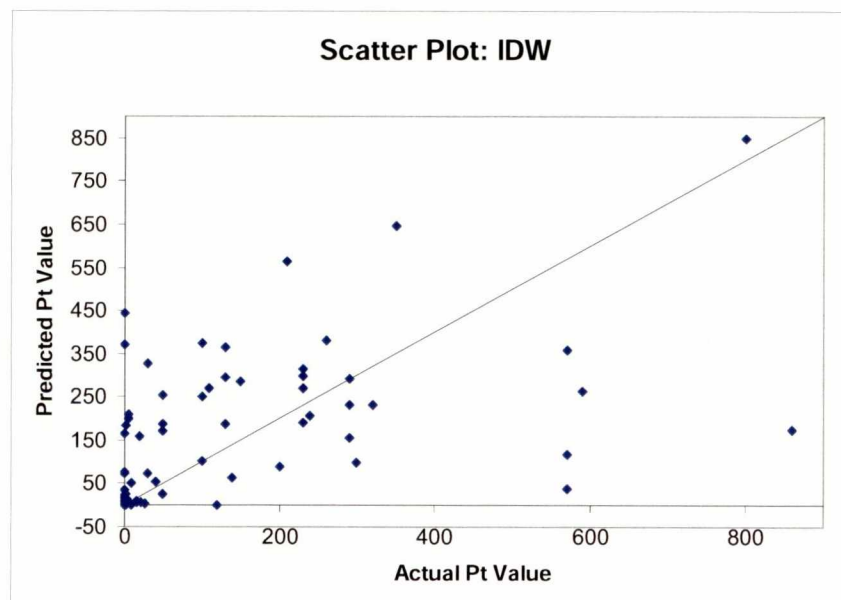


Figure D.2: Scatter plot for the IDW model testing data for platinum from outside the bay-1.

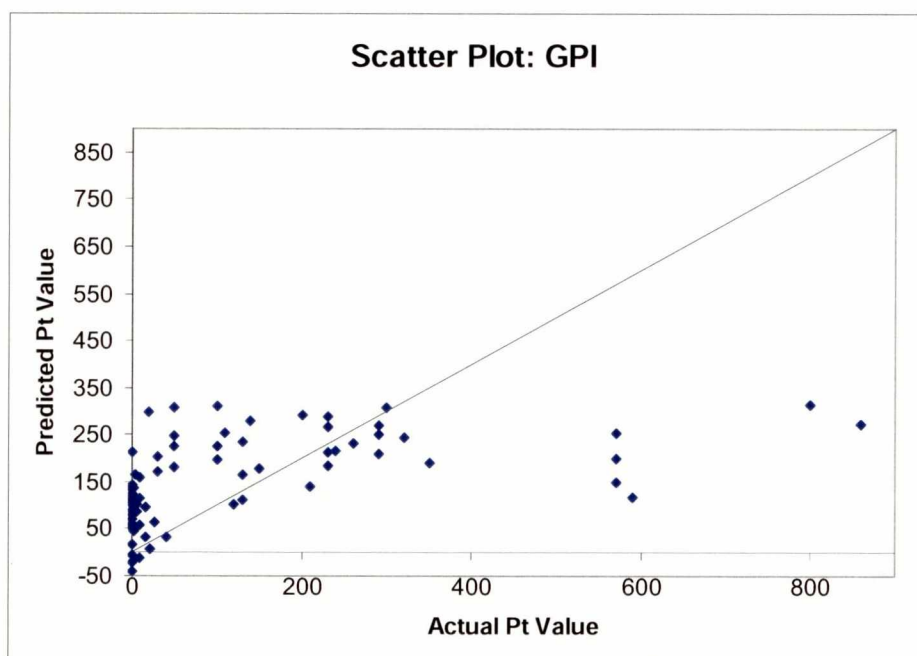


Figure D.3: Scatter plot for the GPI model testing data for platinum outside the bay-1.

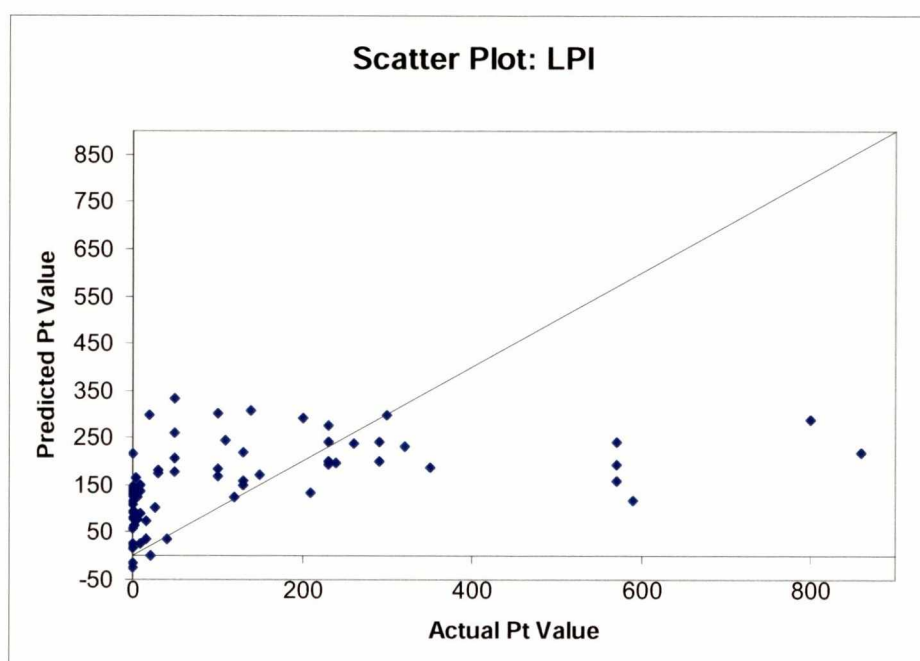


Figure D.4: Scatter plot for the LPI model testing data for platinum outside the bay-1.

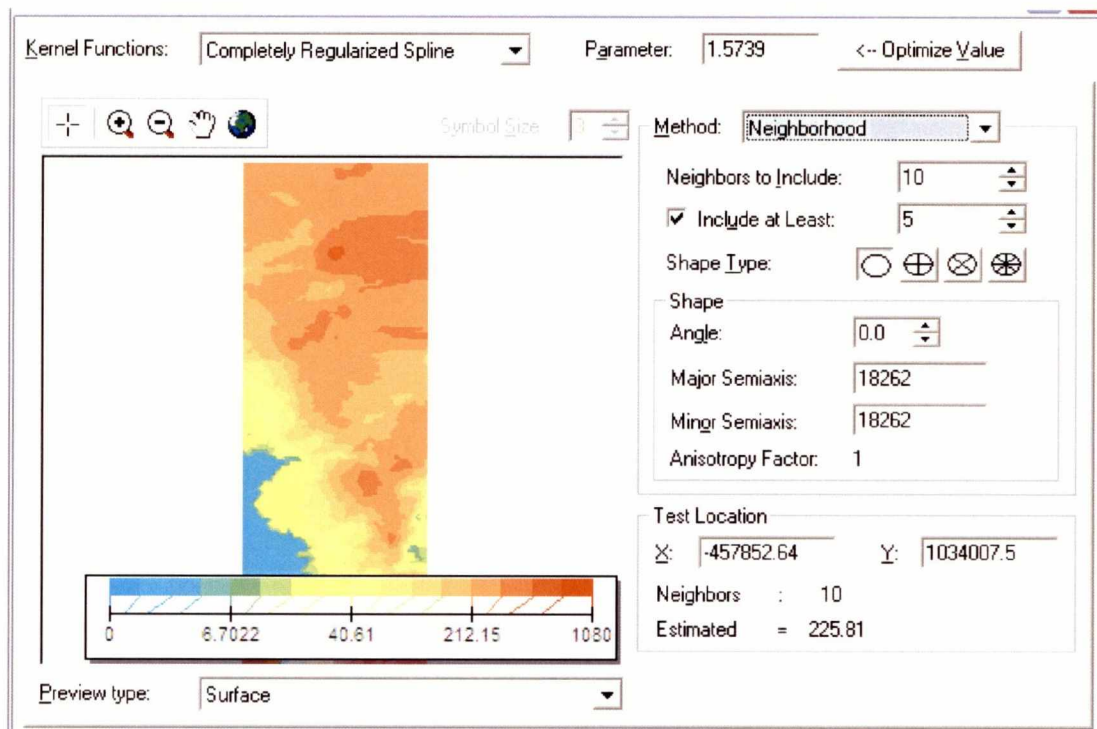


Figure D.5: Parameters used for the RBF model for platinum from outside the bay-1.

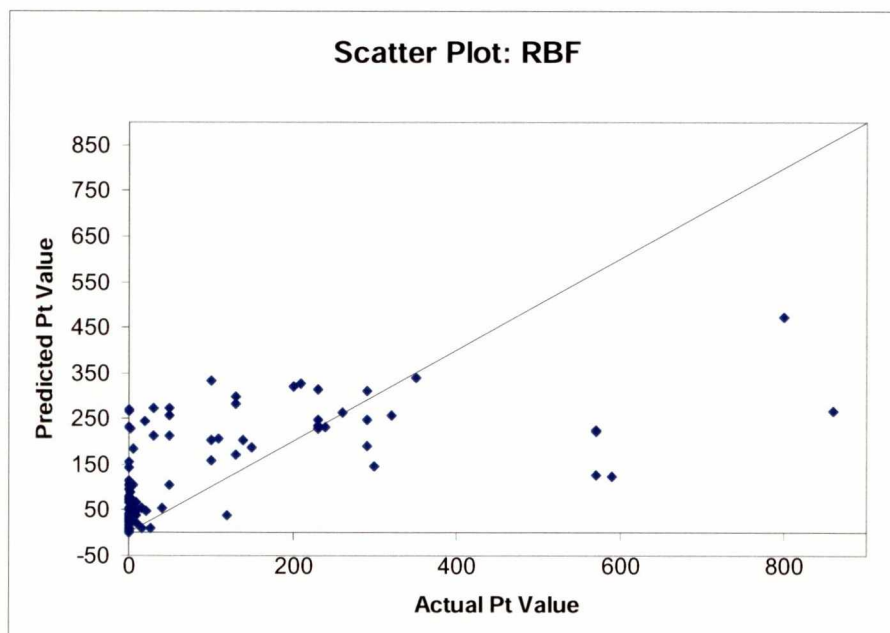


Figure D.6: Scatter plot for the RBF model testing data for platinum from outside the bay-1.

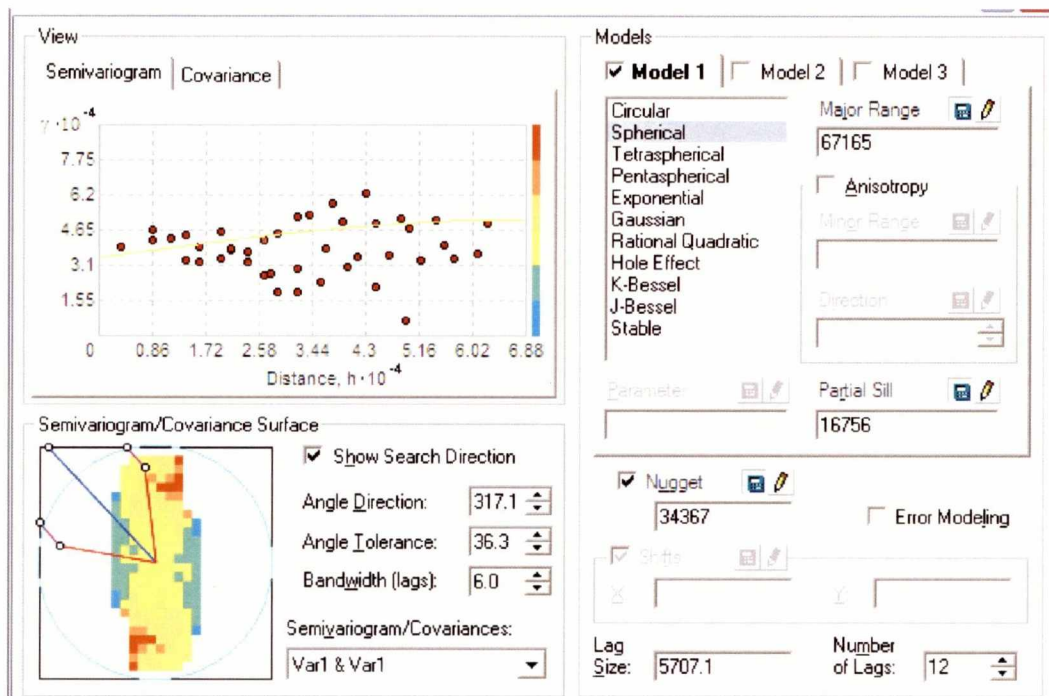


Figure D.7: Parameters used for the OK model for platinum from outside the bay-1.

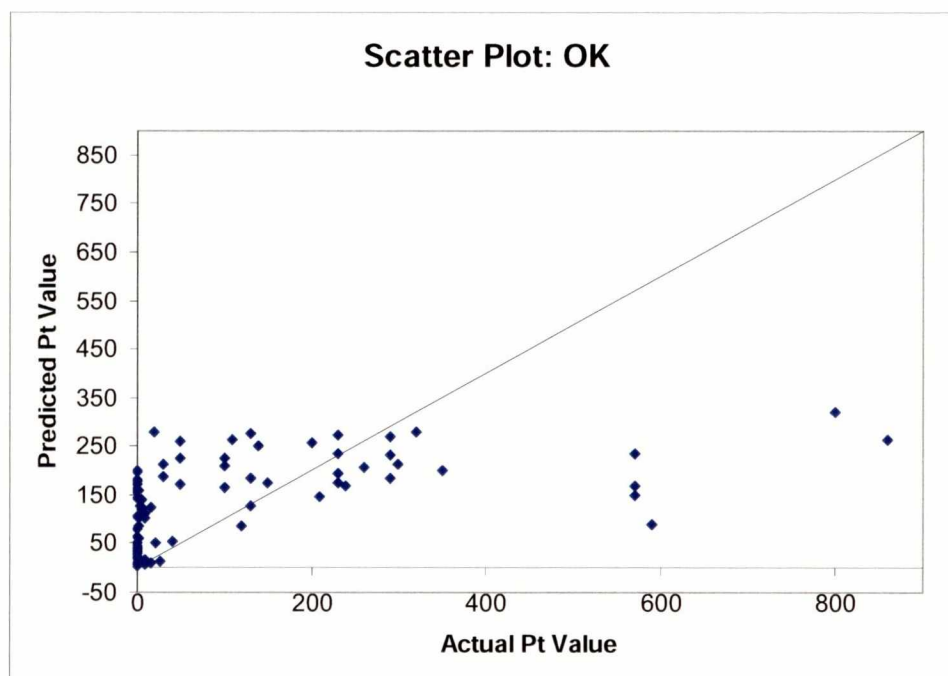


Figure D.8: Scatter plot for the OK model testing data for platinum from outside the bay-1.

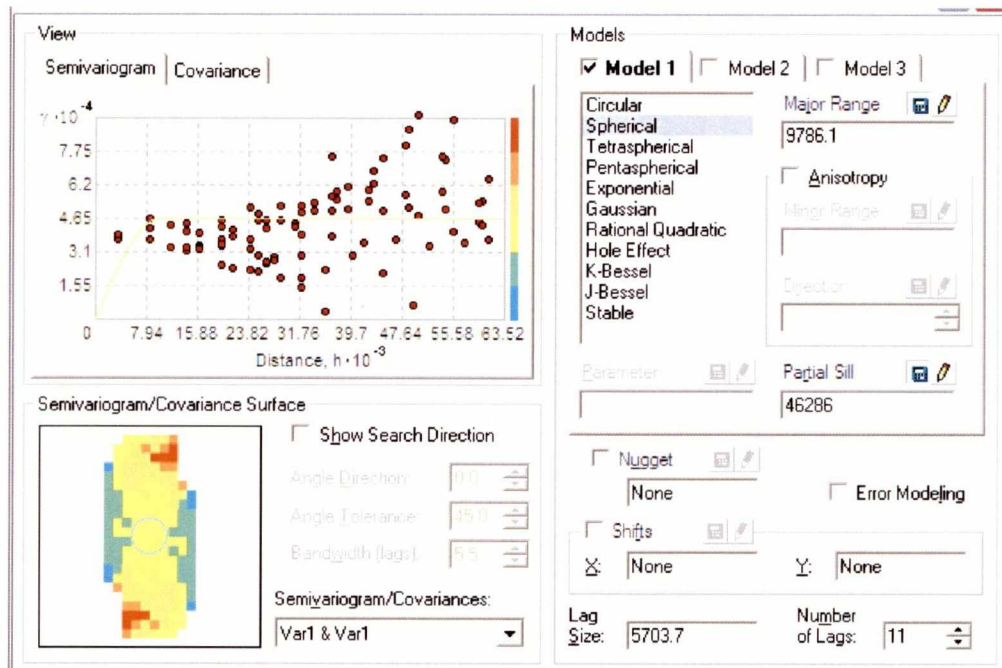


Figure D.9: Parameters used for the CK-Au-Pt model for platinum outside the bay-1.

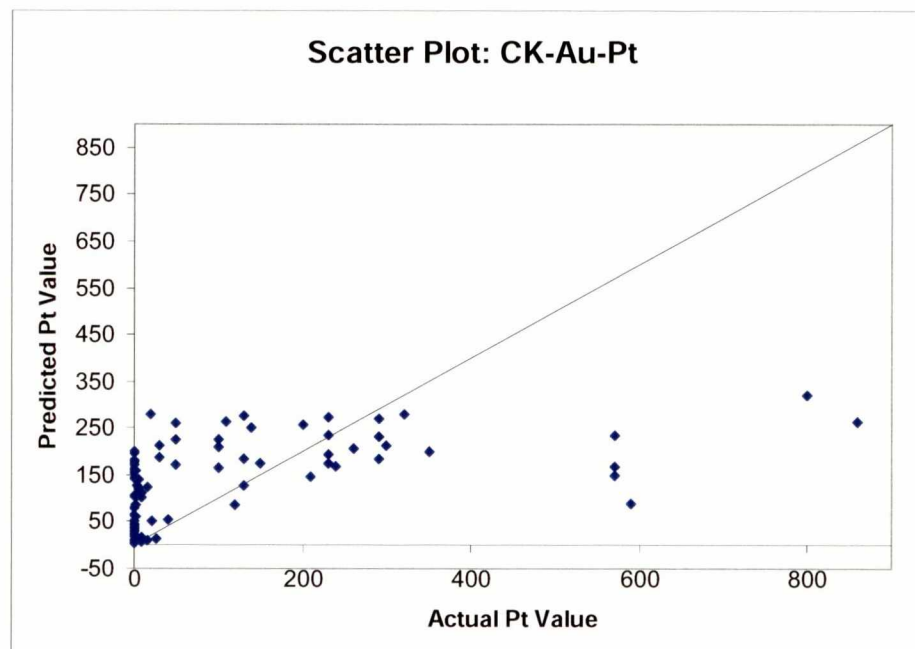


Figure D.10: Scatter plot for the CK-Au-Pt model testing data for platinum outside the bay-1.

Appendix E

Modeling parameters and scatter plots outside bay-2.

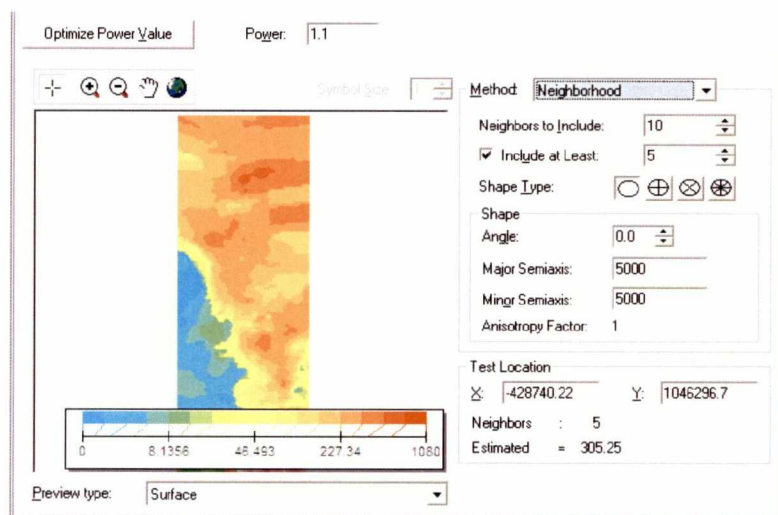


Figure E.1: Parameters used for the IDW model for platinum from outside the bay-2.

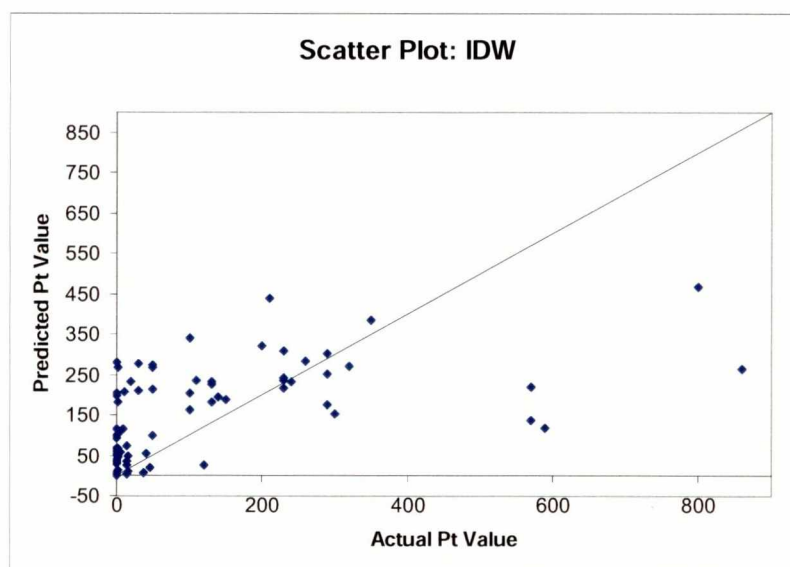


Figure E.2: Scatter plot for the IDW model testing data for platinum from outside the bay-2.

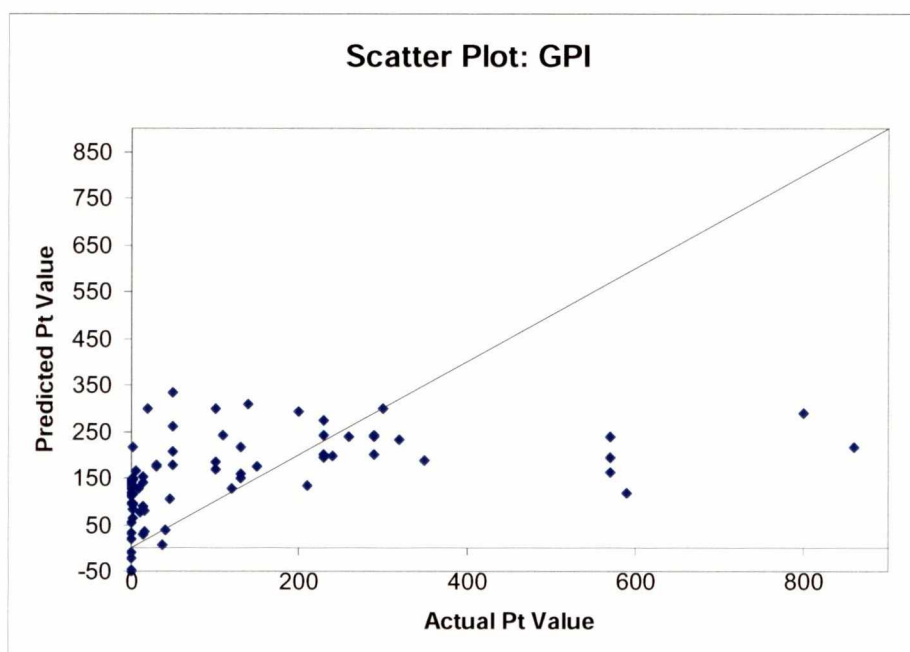


Figure E.3: Scatter plot for the GPI model testing data for platinum from outside the bay-2.

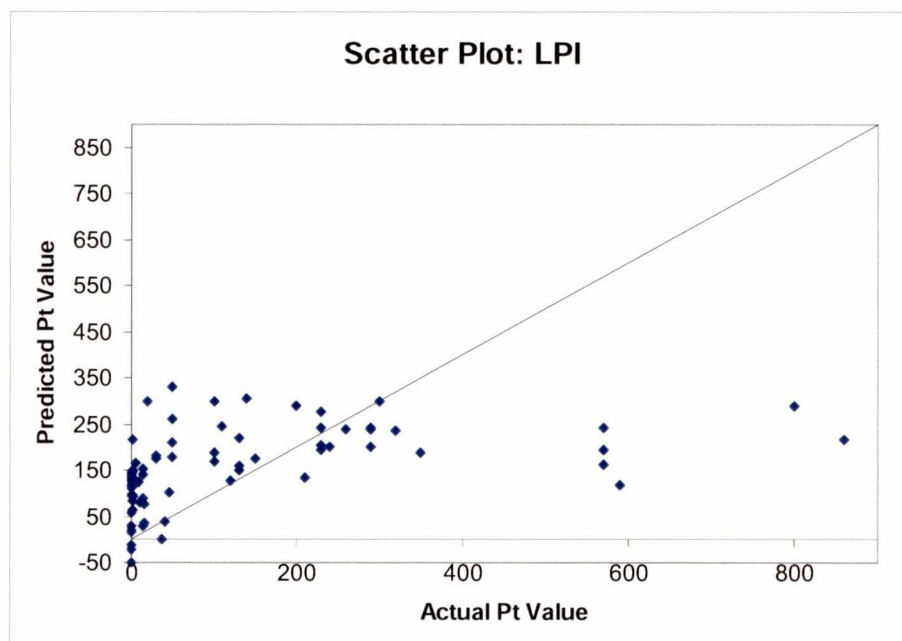


Figure E.4: Scatter plot for the LPI model testing data for platinum from outside the bay-2.

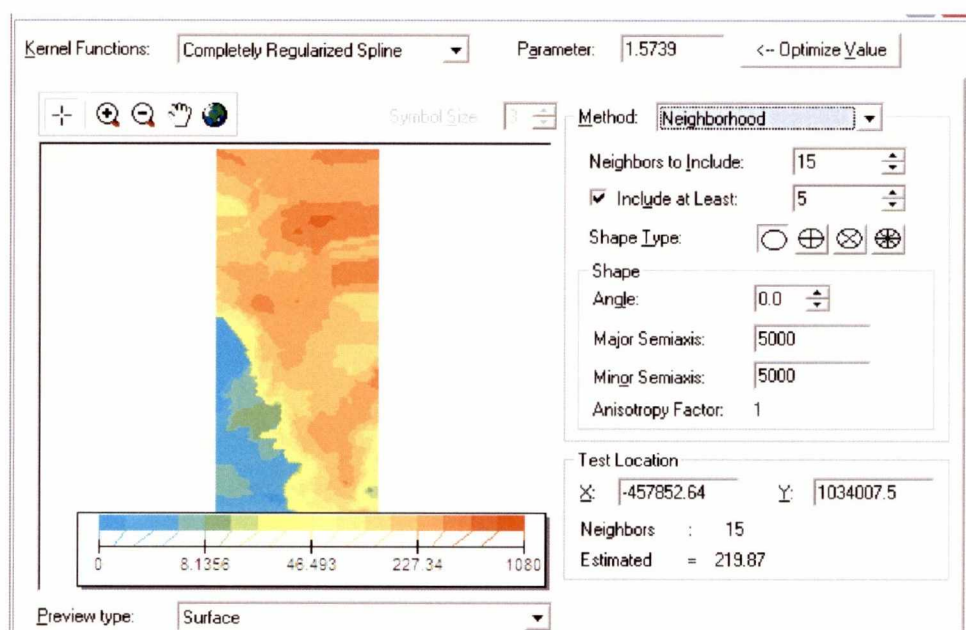


Figure E.5: Parameters used for the RBF model for platinum from outside the bay-2.

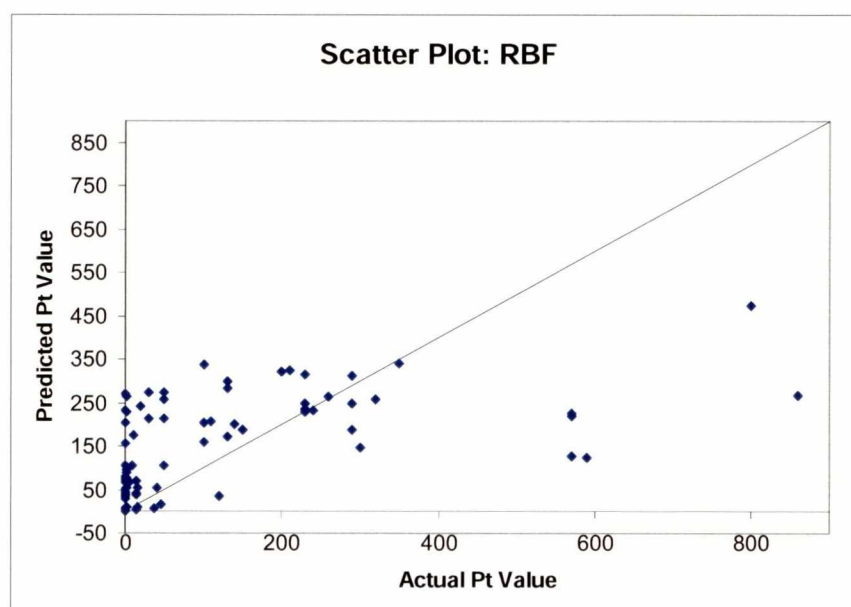


Figure E.6: Scatter plot for the RBF model testing data for platinum from outside the bay-2.

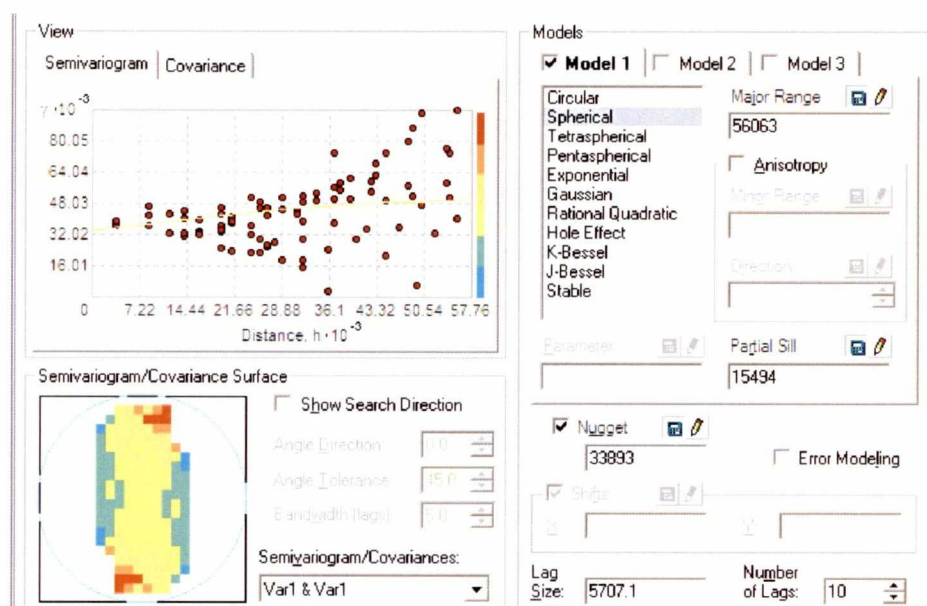


Figure E.7: Parameters used for the OK model for platinum from outside the bay-2.

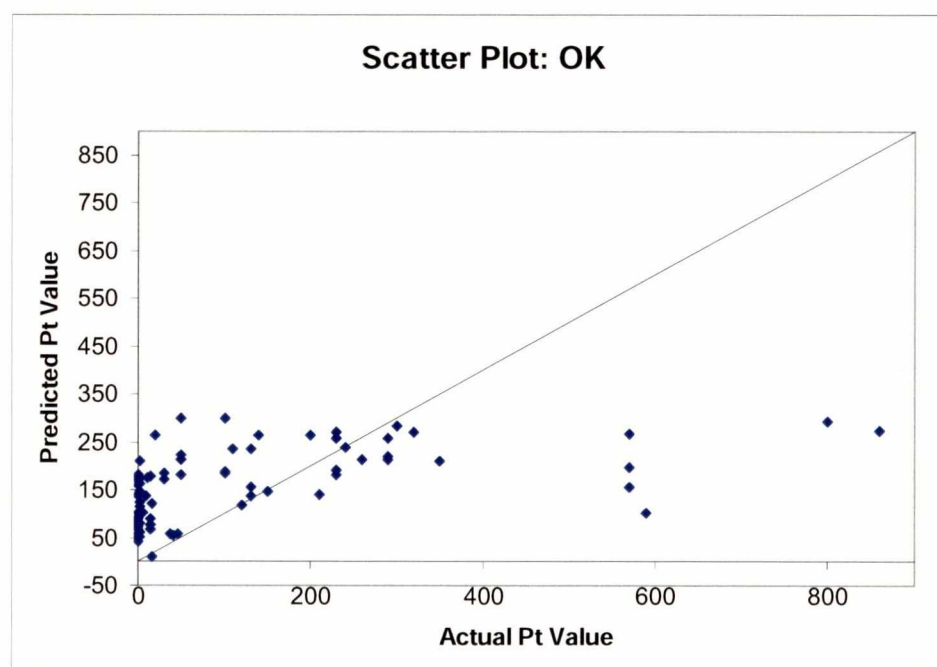


Figure E.8: Scatter plot for the OK model testing data for platinum from outside the bay-2.

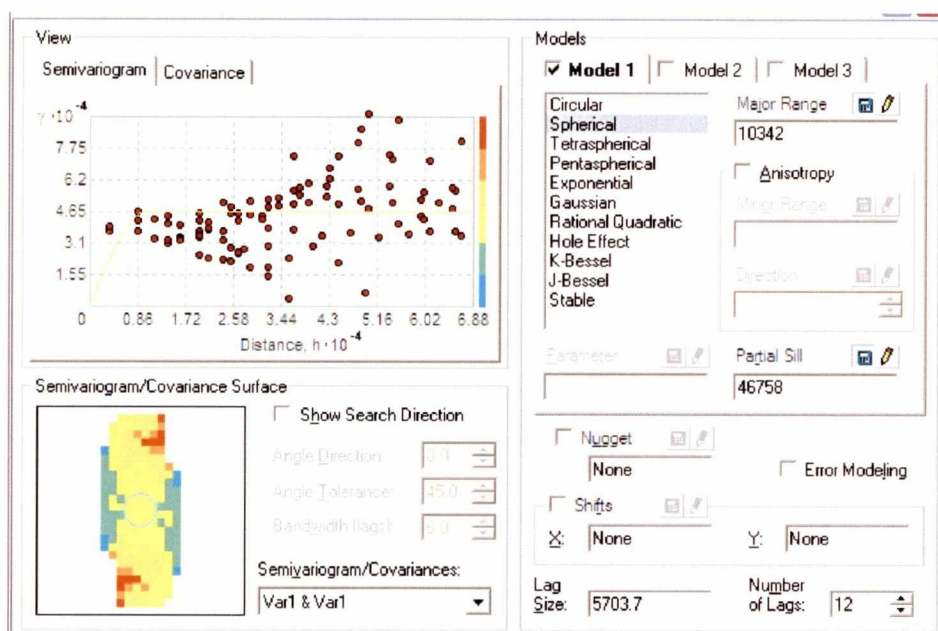


Figure E.9: Parameters used for the CK-Au-Pt model for platinum from outside the bay-2.

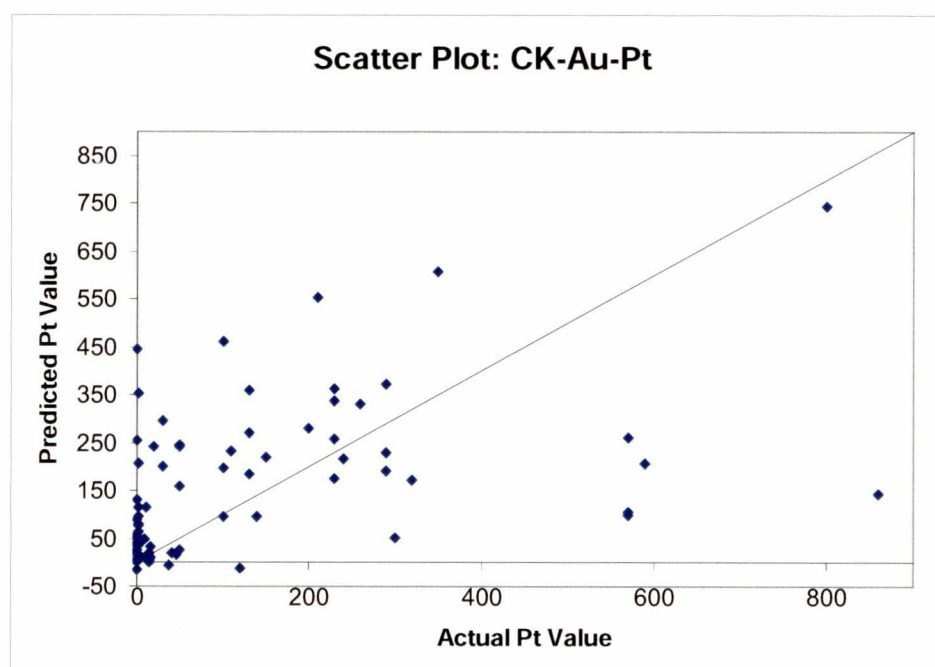


Figure E.10: Scatter plot for the CK-Au-Pt model testing data for platinum from outside the bay-2.